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FLAME-RESISTANT MATERIALS FOR USE IN PYROTECHNIC SAFETY CLOTHING

NAVY CLOTHING AND TEXTILE RESEARCH FACILITY
NATICK, MASSACHUSETTS

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Twelve material assemblies were tested for possible use in pyrotechnic safety clothing that the Navy Clothing & Textile Research Facility (NCTRF), Natick, MA, undertook to develop for the U.S. Army Munitions Production Base Modernization Agency, Dover, NJ. The 12 assemblies, each containing an outershell flame-and-heat block fabric, high-temperature-resistant batt insulation, and expanded polytetrafluoroethylene (PTFE) plastic film laminated to a 3.2-ounce Nomex fabric, were exposed to a "flash-off" of

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15 pounds of pyrotechnic illuminant composition. Two of the outershell fabrics, a 15.5-ounce PBI/OPF (20/80) fabric and a 16-ounce OPF fabric, along with Kynol and Kevlar batt insulations, were found to be significantly better than the others. Either of the two outershell fabrics in assembly with Kevlar or Kynol batts should show a temperature transmission of less than 115 degrees F as determined with a "skin simulant" sensor when exposed to a 6-second "flash-off" of about 5500 degrees F. For the initial prototype pyrotechnic safety clothing, NCTRF recommended a fabric assembly containing a 15.5-ounce PBI/OPF (20/80) flame-and-heat block outershell fabric, a 10-ounce para-aramid (Kevlar) batt insulation, and a vapor barrier/comfort fabric consisting of a moisture-vapor-permeable plastic film (PTFE) laminated to a 5.5-ounce FR cotton fabric. NCTRF also recommended consideration of PBI webbing hold-down straps and PBI sewing thread. (U)

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONTINUED)

LIST OF TABLES

FLAME-RESISTANT MATERIALS
FOR USE IN PYROTECHNIC SAFETY CLOTHING

INTRODUCTION

The Navy Clothing and Textile Research Facility (NCTRF) undertook for the U. S. Army Munitions Production Base Modernization Agency, Dover, N.J., a study to develop safety clothing to be worn by pyrotechnic processing handlers. Twelve experimental fabric assemblies were tested by exposing them to pyrotechnic composition "flash-offs" and recording the data by the use of: "skin-simulant" sensors (calorimeter) connected to an on-line microprocessor; Fastex and video cameras; visual observation; and still photographs of each fabric asssembly.

For each test of experimental material assemblies and hoods containing plastic faceshields, the pyrotechnic composition was 15 pounds of dry granular illuminant placed in a simulated mixer at an open-air site. Each assembly contained an outershell flame-and-heat block fabric, low-density insulation batt, and vapor-barrier fabric. Two outershell fabrics, a 15.5-ounce PBI/OPF (20/80) fabric and a 16-ounce OPF fabric, were found to be significantly better than the others along with Kynol and Kevlar batt insulations and appeared to be acceptable candidates for use in pyrotechnic safety clothing. Either outershell fabric in assembly with either batt, with a minimum thickness of 0.35 inch, should exhibit a temperature transmission of less than 115 degrees F as determined by a "skin simulant" sensor when exposed to a 6-second "flash-off" of about 5500 degrees F.

This report describes the investigation of high-temperature, flame-resistant materials alone and in combinations to obtain data that would allow a judgment to be made as to their individual effectiveness when exposed to a pyrotechnic composition "flash-off" and when used in pyrotechnic safety clothing. The report recommends for further heat tests and a user evaluation a material assembly for use in an experimental prototype garment that accommodates a hood, gloves, and air supply.

BACKGROUND

Ignition of pyrotechnic compositions develops extremely high temperatures (5500 degrees F) from rapidly expanding gases and fireballs, flaming solids, and radiation. The resulting energy passes through the protective materials by conduction, convection, and radiation. Upon close observation of a pyrotechnic composition "flash-off," it becomes apparent that a highly reflective outer surface would be ineffective for use in pyrotechnic safety clothing (Figure 1). When pyrotechnic material ignites, carbonized ash is instantaneously released that covers and clings to all nearby surfaces. Therefore, non-reflective, flame- and heat-resistant outershell fabrics in combination with low-density batts and a vapor barrier liner should be used in pyrotechnic safety clothing.

In July 1981, we visited two Army ammunition plants--Longhorn, Marshall, TX, and Lonestar, Texarkana, TX, to acquire insight into the kinds of fabrics and garment designs that would be needed. Pyrotechnic compositions are highly sensitive to heat, static electricity, and mechanical shock. Of major concern when choosing flame- and heat-resistant outershell fabrics would be the ability of the fabric to discharge static electricity, which is currently kept under control by requiring all personnel to wear clothing that assists in the dissipation of static electrical build-up. Therefore, pyrotechnic handlers are not allowed to wear garments made from materials that have low moisture regain. In fact, the only garments officially allowed in or around the mixing bays are those approved by management. In addition to wearing anti-static clothing, personnel must wear conductive shoes, and when entering the mixing bay, must discharge any built-up body charges by touching a grounded metal pipe. Because of the attention given to static-electrical discharge, we concluded that only those outershell fabrics that have moisture regain equal to or better than cotton should be considered for final testing.

The characteristics of flame and heat resistance with minimum moisture regain of about 8% reported for cotton narrowed the choice of outershell materials that could be considered. Candidate materials should also show fairly good tensile and tear strength, abrasion resistance, mimimum stiffness, low shrinkage after laundering, and afford a moderately high comfort factor when made into garments and worn by personnel in the mixing bays. It should be noted that, during the summer months at the Longhorn and Lonestar ammuniton plants, the ambient temperature in the shade could go above 100 degrees F. Therefore, although we felt that the selected material assembly should be fairly heavy, with a minimum thickness of about 0.35 inch, we thought it was still important to evaluate lighter and thinner materials during preliminary testing of candidate fabric assemblies.

EXPLORATORY CLOTHING DEVELOPMENT

During the exploratory phase of the work to develop pyrotechnic safety clothing, we recognized that the destructive force of a pyrotechnic composition "flash-off" was great, but only after observing the ignition of 15 pounds of pyrotechnic composition and studying the replay on video tape, did we fully appreciate its destructive force. Although the total time of the "flash-off" was about 5 to 6 seconds, during that short timeframe the recorded temperature was about 5500 degrees F, with the ambient environment consisting of hot gases, flame, particles of flaming material, and radiant heat. The material exploded from the simulated mixing bowl to a height of about 50 to 70 feet, and if the explosion had been contained in an enclosed room, it would have momentarily engulfed the total area and the people in it (Figure 1). In fact, after the first two test firings, many of the prepared samples were discarded, because the lighter and/or low-temperature heat-resistant outershell fabrics were shredded and badly charred. (See Figures 2, 3, 4, and 5.)

With this life-threatening situation confronting personnel, the garment must have substantial thickness and heat resistance. The outershell material must withstand the initial thermal shock and continue to act as a flame and heat block for the insulation batt and vapor barrier liner to be effective. Also, during normal working conditions or a "flash-off" of pyrotechnic materials, a means of breathing fresh air appears necessary.

Experimental Insulation Batts

The experimental fibrous insulation batts were chosen primarily for their high heat resistance and low density. All of the batts had about the same density, but varied in their thickness and degradation temperature. It should be noted that the Kevlar batt also affords a degree of ballistic resistance and was originally designed with a knowledge of how needle-punched felt materials defeat projectiles traveling at high speeds (1 and 2). The Kevlar felt was made by lightly needlepunching at 240 needle penetrations per inch a batt weighing about 2.6 oz/yd^2 and then needling three of the batts together in one pass at 210 needle penetrations per inch. This construction should exhibit the highest ballistic resistance while its low density helped to provide improved thermal resistance (1).

Vapor Barrier Liner

With the final addition of a water-resistant liner, the material assembly would be complete. (It should be noted that the pyrotechnic mixing bay contains a means of releasing a deluge of water directly over the mixing bowl at the instance of ignition.) The water barrier fabric would also afford a degree of comfort and protect the low-density insulation batt from abrasion. Initially, a polytetrafluoroethylene (PTFE) expanded plastic film was laminated to 3.2-ounce

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1. Kupferman, Z., and Silvia, J., **The Development of a Buoyant-Ballistic Vest for Naval Forces**, Navy Clothing and Textile Research Facility, Natick, MA, Technical Report No. 104, September 1972.

2. Ipson, T. W., and Wittrock, E. P., **Response of Non-Woven Synthetic Fiber Textiles to Ballistic Impact,** Denver Research Institute, University of Denver, CO, Contract No. DA19-129-AMC-157(N), U. S. Army Natick Laboratories, July 1966.

Nomex fabric. After the first series of tests, however, we decided to substitute a flame-resistant-treated, 5.5-ounce cotton fabric, because the Nomex fabric melted and shrank when used in fabric assemblies during the preliminary pyrotechnic composition "flash-offs." The cotton fabric also costs less than the Nomex fabric and has higher moisture regain.

Material Requirements

The technical requirements considered for materials to be used in the safety clothing were that they be flame resistant with a minimum outershell fabric moisture regain of 8% (cotton) and total material assembly weight of not more than 30 oz/yd^2. The material assembly should be designed to offer thermal protection that would limit bodily injury to a first degree burn when personnel are exposed to a "flash-off" of 15 pounds of pyrotechnic material. After exposure to a "flash-off," the outershell fabric of the clothing should continue to retain its shape and, to some extent, its tear and tensile strength. Initially, thermal protection was defined to mean that the rise in energy be no greater than 0.3 $gcal/cm^2/sec$ for 3 seconds exposure when measured by a calorimeter placed behind and in contact with the fabric assembly. This definition of thermal protection was subsequently revised in order to relate the requirements to the threshold of pain of human skin. The redefined requirements stated that the temperature rise behind the assembly should be no greater than 20.0 degrees F after a 5-second exposure to pyrotechnic "flash-off" as measured by a "skin simulant" (calorimeter) of the type made by Albany International Research, Dedham, MA. The "flash-off" of 15 pounds of material wa times to be about 5 seconds to exhaustion.

Threshold of Pain Temperature

References 3 and 4 discuss the threshold of pain to be between 108 and 119 degrees F for human skin. Buettner cited skin temperatures between 108 and 113 degrees F, while Moritz and Henriques cited skin temperatures between 117 and 119 degrees F. The skin temperature for the threshold of pain was, therefore, established at 111 degrees F, a 20 degree F rise in the "skin simulant" when considering an initial skin temperature of 91.0 degrees F. Figure 6 shows the full range of testing by Buettner, Moritz, and Henriques.

It is important to note that the surface temperature of the skin and the time that the surface of the skin is kept at that temperature produces the physiological effects of pain, unbearable pain, and burn. Buettner showed that exposure of the skin surface to about 119 degrees F for 10 minutes will cause a burn to occur; at approximately 121 degrees F, it would take about 2 minutes for a burn to occur; at 140 degrees F, only 3 to 5 seconds; and, at 158 degrees F, less than 1 second.

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3. Buettner, K., "The Effects of Extreme Heat and Cold on Human Skin, II. Surface Temperature, Pain and Heat Conductivity in Experiments with Radiant Heat," **J. Appl. Physiol.**, Vol. 3, No. 12, June 1951, p. 703.

4. Moritz, A. R., and Henriques, F. C., "Studies of Thermal Injury II, The Relative Importance of Time and Surface Temperature in the Causation of Certaneous Burns," **Am. J. Pathol.**, Vol. 23, 1947.

MATERIALS

Fabrics Originally Considered for Testing

At the start of the test program, a large group of fabrics alone and in assemblies were prepared for testing. Table I lists the fabrics, their fiber content, weight, and plies of fabrics used in assembly, which were sewn into sleeves that were 4.5-inches by 4.5-inches sleeves by 48 inches long. The vapor barrier liner for all of the prepared assemblies was an expanded plastic film, polytetrafluoroethylene (PTFE), laminated to 3.2-ounce, pajama-check Nomex fabric. The one, common characteristic of all test fabrics was flame resistance. Otherwise they varied in fiber content, weight, thickness, density, and color. Because the fabric testing was scheduled for completion in 1 day, all of the fabrics listed in Table I were used to make experimental sleeves for test and evaluation. Glass fabrics were not included in the test program because of their low resistance to flexing.

Fabrics Tested

After the initial "flash-off," it became apparent that not all of the sleeves would be tested. Table II lists the material/material combinations that were tested and reported on. Table III lists the physical characteristics of the materials listed in Table II. The test materials represented almost all of the commercial, high-thermal-performance fabrics available in the United States that could be used in garments.

Because **Kynol** fabrics were made in Japan, they were not considered for this test and evaluation program. A Kynol needlepunched batt, however, was made part of the test program as an insulation liner, along with Nomex, Kevlar, and PFR Rayon/Wool, because it was readily available in the required thickness and density.

OPF, oxidized polyacrylonitrile (PAN) fiber, is made by taking the PAN fiber in tow form and passing it through an enclosed box heated to about 250 degrees C. The tow emerges as a semi-carbonized fiber, from which most of the flammable gases have been removed. The carbonized tow is then broken into the desired staple length and spun into yarns.

The OPF fabrics discussed in this report were made from 10 singles yarn purchased from Celanese Corporation. OPF fabrics are stable to about 1200 degrees F and would require additional heat exposure for the preoxidized fiber to change into 100% carbon fiber. Other materials, such as, rayon, Kynol, and pitch, have also been used to make OPF fabrics. OPF fabrics have shown some major physical problems that have kept them from being readily acceptable for use in clothing. The fiber exhibits a fairly low tensile strength of about 1.7 g/pd, poor abrasion resistance, and a natural black color. However, Celanese Corporation has reported that OPF has a moisture regain of about 10% and is heat and flame resistant.

Polybenzamidazole (PBI), another one of the extremely high-temperature-resistant fibers, can withstand temperatures to about 2,000 degrees F before degradation starts and is made in the United States for use in clothing. PBI fabrics show good tensile and tear strength in shirting and trouser-weight fabrics, have a high moisture regain of 13%, are easily spun into yarn, and feel comfortable when sewn into garments. However, the natural color of the fiber is medium brown, and it costs about $38 per pound. Because of the high cost of raw materials, Celanese

(Text continued on page 10.)

Table I. List of Fabrics/Fabric Combinations Initially Made into Sleeves for Pyrotechnic Testing

Fabrics/Fabric Combinations (1) (2)	Fiber Content (%)	Wgt (oz/yd^2)	Plies (3)
1. Std. Kevlar Fabric (4)	100	8.0	2
2. Std. Aluminized Kevlar (4)	100	12.0	2
3. Kevlar Knit	100	8.0	2
4. Kevlar/OPF (5) Blend	35/65	11.0	2
5. Aluminized Kevlar/OPF Blend	35/65	16.0	2
6. Kevlar Wrapped Glass Core	80/20	11.0	2
7. Kevlar/Nomex Blend	50/50	7.0	2
8. Woolshield (wool/steel fiber)/	99/1	15.0	3
Std Kevlar	100		
9. Cotton Flame-Resistant ($THPOH-NH_3$)/	100	13.8	3
Cotton, Fire Resistant ($THPOH-NH_3$)	100		
10. Std Kevlar/	100	14.9	3
Cotton, Flame-Resistant ($THPOH-NH_3$)	100		
11. PBI (6) Wrapped OPF Core	20/80	16.2	2
12. PBI Fabric	100	8.0	2
13. Woolshield (wool/steel fiber)	99/1	7.0	2
14. PFR Rayon (7)/Nomex Blend	80/20	7.3	2
15. PBI/Kevlar Blend	20/80	11.0	2
16. PFR Rayon-Nomex Blend/	80/20	14.3	3
Kynol Batt, 7 $oz./yd^2$	100		
17. PBI Fabric/	100	8.0	3
Kynol Batt, 7 oz/yd^2	100		
18. Woolshield (wool/steel fiber)/	99/1	14.0	3
Kynol Batt, 7 oz/yd^2	100		
19. PBI Wrapped OPF Core/	20/80	23.2	3
Kynol Batt, 7 oz/yd^2	100		
20. PBI Fabric, 8 oz/yd^2/	100	11.9	3
PFR Rayon/Wool Batt, Blend	65/35		
21. PFR Rayon/Nomex Blend/	80/20	11.2	3
PFR Rayon/Wool Batt, Blend	65/35		
22. Woolshield (wool/steel fiber)/	99/1	10.9	3
PFR Rayon/Wool Batt, Blend	65/35		
23. PBI Wrapped OPF Core/	20/80	23.2	3
Nomex Batt	100		
24. PBI Fabric, 8 oz/yd^2	100	18.3	3
Kevlar Batt	100		
25. Woolshield (wool/steel fiber)	99/1	11.0	3
Nomex Batt	100		
26. PFR Rayon/Nomex Blend	80/20	11.3	3
Nomex Batt	100		
27. PBI Wrapped OPF Core	20/80	20.2	3
Nomex Batt	100		
28. PBI Wrapped OPF Core	20/80	20.1	3
PFR Rayon/Wool Batt, Blend	65/35		
29. OPF Fabric	100	27.5	3
Kevlar Batt	100		

Table I. (Continued)

30. OPF Fabric	100	18.9	3
PFR Rayon/Wool Batt, Blend	65/35		
31. Leather, Skin Facing Out (2.5/64)	-	-	3
Kevlar Batt	100		
32. PBI Fabric	100	16.1	3
Nomex Batt, 7 oz/yd^2	100		
33. PBI Wrapped OPF Core	20/80	19.9	3
Nomex Batt, 4 oz/yd^2	100		
34. OPF Fabric	100	23.4	3
Kevlar Batt	100		
35. OPF Fabric	100	18.8	3
PFR Rayon/Wool Batt, Blend	65/35		
36. Facepiece Support (FS)(8) - Methyl Methacrylate, 1/8 inch thick			
a. Clear plastic			2
b. Gold-Coated Polyester, 7 mil, facing in			2
c. Gold-Coated polyester, 7 mil, facing out			2

Footnotes

(1) Vapor Barrier Liner, expanded PTFE laminated to 3.2 oz pajama check Nomex fabric, used as the last fabric behind all fabric combinations.
(2) Fabrics listed in order used from the outside in.
(3) The number of plies listed includes vapor barrier fabric
(4) Military specification no. MIL-C-87076
(5) OPF - Oxidized polyacrylonitrile fiber
(6) PBI - Polybenzimidazole
(7) PFR Rayon - Permanent, flame-resistant rayon
(8) Military Specification MIL-H-29144, Fireman's Hood

Table II. Fabrics/Fabric Combinations Tested

Test Code No.	Fabric Combinations (1)
16	PBI Wrapped OPF Core
22	PBI Fabric/Kynol Batt
24	PBI Wrapped OPF Core/Kynol Batt
25	PBI Fabric/PFR Rayon-Wool Batt
31	PBI Fabric/Kevlar Batt
28	PBI Wrapped OPF Core/Nomex Batt, 6.9 oz/yd^2
35	PBI Wrapped OPF Core/PFR Rayon-Wool Batt
38	Leather (2.5/64) Skin Facing Out/Kevlar Batt
29	PBI Fabric/Nomex Batt 7 oz/yd^2
34	PBI Wrapped OPF Core/Nomex Batt, 4 oz/yd^2
36	OPF Fabric/Kevlar Batt
37	OPF Fabric/PFR Rayon-Wool Batt
	FACEPIECE ASSEMBLIES
38	Clear plastic film over 1/8 inch facepiece support (FS)
39	Gold-coated polyester film, facing in, over FS
40	Gold-coated polyester film, facing out, over FS

(1) Vapor barrier liner, expanded polytetrafluoroethylene film laminated to 3.2-oz, pajama-check Nomex fabric used as the last fabric in assembly with fabric combinations.

Table III Physical Characteristics of Materials Used in Heat Tested Sleeves

Materials	Color	Weight (oz/yd^2)	Thickness .018 PSI (inches)	Density ($lbs./ft^3$)	Fiber Content (%)
I Outershell Fabrics					
A. PBI - Polybenzimadazole	Brown	9.1	.033	22.9	100
B. OPF - Oxidized Polyacrylonitrile Fiber	Black	15.0	.056	22.2	100
C. PBI/OPF (Core Spun)	Brown/Black	15.9	.065	20.3	20/80 avg.
D. PBI	Brown	8.1	.044	15.3	100
E. Leather, skin facing out	Gray	-	-	-	-
II Insulation: Needlepunched Batts					
A. Kevlar (aramid)	Yellow	8.4	.362	1.93	100
B. Kynol	Brown	6.5	.180	3.00	100
C. PFR Rayon/Wool	White	3.8	.177	1.78	65/35
D. Nomex (Aramid)	White	6.9	.280	2.05	100
E. Nomex (Aramid)	White	4.0	.187	1.78	100
III Lining Expanded PTFE Laminated Nomex Fabric	White	3.6	.011	27.2	-
IV Facepiece, Hood					
A. Facepiece support (Methyl Methacrylate)	Clear		.125		-
B. Polyester Film, Vacuum Deposited Gold	Gold		.007		-
C. Plastic Film	Clear		.007		-

Corporation has indicated that the price per pound of PBI would not be significantly reduced as the total poundage per year increases. Therefore, PBI must be carefully used so as not to overprice garments using the fiber. The experimental 8-oz/yd^2 PBI fabrics contained 100% PBI fiber, while the 16-oz fabric of OPF/PBI contained about 20% PBI. It should be noted that the PBI fiber in the 16-oz fabric was first made into a yarn and then twisted around a 10 singles OPF core yarn, thus helping to protect the OPF component from abrasion.

All the other test fabrics can be classified as flame resistant but vary with respect to the temperature at which they start to degrade. **Kevlar** fabrics can generally withstand temperatures to about 800 degrees F prior to the start of degradation, **Nomex** starts to degrade at about 675 degrees F, and **wool, FR cotton, and PFR rayon** would start to show degradation at about 400 degrees F.

It is recognized that strength retention varies widely with exposure time and/or increased temperature. This loss of strength with increased heat-exposure time and temperature has been studied by Albany International Research, Inc., Dedham, MA, under a contract from NCTRF (5 and 6).

Faceshields

The three variations of plastic faceshield assemblies were chosen, because the plastic materials were being used in firefighter's aluminized proximity hoods that were found to be acceptable. Reference 7 describes in detail the clear-plastic facepiece support, the vacuum-deposited, gold-coated, 7-r olyester film, and the hood that holds the plastic faceshield.

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5. Shoppee, M. M., Welsford, J. M., and Abbott, N. J., **Resistance of Navy Shipboard Work Clothing Materials to Extreme Heat,** NCTRF Technical Report No. 148, October 1982.

6. Shoppee, M. M., Welsford, J. M., and Abbott, N. J., **Resistance of Navy Shipboard Outerwear Garments and Fire-Resistant Fabrics to Extreme Heat,** NCTRF Technical Report No. 153, December 1983.

7. **Hood, Firemen's, Aluminized, Proximity,** Military Specification MIL-H-29144A, 30 June 1977.

APPARATUS AND PROCEDURE

Skin Simulant

The "skin simulant," a polyethylene resin disc, 1-1/2 inches in diameter by 3/8 inch thick, was designed to have a temperature response similar to human skin. The "skin simulant" contains a 3-mil-diameter, copper-constantan thermocouple, placed 500 microns below the surface, which is then attached to two terminals on the back of the simulant. The "skin simulant" is connected by means of thermocouple wires to a multi-channel microprocessor, which records and stores the temperature rise once every second. A more detailed description of a "skin simulant" can be found in references 5 and 8.

Test Site

The test site was prepared as shown in Figure 7. One half of a clean oil drum was raised about 1 foot from the ground to simulate the bowl of a 50-pound batch mixer. Four 4-inch by 4-inch wooden posts were placed in the ground and slanted over the oil drum to simulate pyrotechnic handlers working around the mixer. The temperature sensing device was mounted flush with the face of each post at about chest-high level. A nominal 4-foot-long test sleeve was slipped over each of the three 4-inch wooden posts prior to testing. For the final round of tests the post were cut shorter so that thermocouples were in the center of the plastic faceshield of the firefighter's hood when mounted on top of the post and tied down.

Procedure

The pyrotechnic material was a 15-pound charge consisting of 58% magnesium (30/50 mesh), 38% sodium nitrate, and 4% epoxy binder. The charge was placed in the simulated mixing bowl and ignited with an M-2 electric squib placed in a bag containing 3 gms of a No. 5 black powder. The ignition and "flash-off" of each test was recorded by a Fastex and a video camera.

It should be noted that all six "flash-offs" were conducted outdoors. Therefore, no attempt was made to contain the ensuing fireball which would have caused an intensification of the heat buildup around the test site. For preliminary testing, however, a clear view of the test site and "flash-off" was required.

It was noted that a pyrotechnic composition "flash-off" takes a fairly short period of time of about 5 to 6 seconds before it is completely exhausted. This observation was made for 15 pounds of the material, but we thought that 50 pounds of the pyrotechnic composition would also be rapidly exhausted. The fireball from the larger amount of material should be just about as intense as for the 15 pounds of material and should be exhausted in about 5 to 10 seconds.

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8. Stoll, A. M. and Chianta, M. A., **A Method and Rating System for Evaluation of Thermal Protection**, Naval Air Systems Command, Naval Air Development Center, Warminster, PA, NADC-MR-6809/AD 846419, December 1968.

DISCUSSION OF RESULTS

Materials

Table IV lists the temperature rise behind each of the 12 test sleeves and three plastic faceshields at 5-second intervals for 35 seconds. The average surface temperature of human living skin was considered to be 91.0 degrees F (32.5 degrees C), and a skin temperature of 111.0 degrees F (44 degrees C) was established for the threshold of pain. Therefore, the "skin simulant" would have to show a temperature rise of 20.0 degrees F (11.5 degrees C) to reach the threshold of pain and 91.0 degrees F (40 degrees C) for instantaneous burn. It is recognized that the "skin simulant" does not represent human living skin in all its dimensions and that it falters in a number of areas. For instance, the depth at which the temperature is recorded in the simulant is 500 microns, while the depth at which injury occurs in the basal layer of living skin is about 80 to 100 microns. Moreover, time plays an important part in how soon human skin is affected by increasing temperatures. It can be assumed that, if the temperature of human skin can be kept below 111.0 degrees F (44 degrees C), burn should not occur for over 10 minutes (Figure 6).

The interpretation of data discussed in this report used information from the listed references. Many physical characteristics ultimately affect pain and burn in human skin, and a change in one of these would cause a change in the time that human skin reaches the threshold of pain and burn. To a great extent, however, the deviations have been addressed and the present arrangement erred on the side of safety.

Figures 8, 9, 11, 16, 17, and 19 show tested assemblies that exhibited a rapid rise in temperature during and after the "flash-off" of pyrotechnic material. Tested assemblies 16, 25, and 29 (Figures 8, 11, and 16, respectively) showed temperature rises that passed through the threshold of pain line in less than 1 second and the instantaneous burn line in about 2 to 4 seconds. Personnel wearing garments made from these materials would not be expected to escape being burnt. The continued rapid rise in recorded temperature after exhaustion of the pyrotechnic composition can be attributed to flaming or other exothermic reactions of test assemblies. Visual observations (Table V) recorded complete destruction of the materials for tested assemblies 16, 25, and 29.

Assembly 16 showed the need for an insulating batt layer behind the flame and heat blocking fabric, but the insulation would require higher temperature-resistant fibers than PFR rayon/wool or Nomex. Assembly 37 outershell fabric can be considered a good flame and heat blocker, but with the PFR rayon/wool felt insulation, it showed a very low thermal protective rating (TPR) of about 1.5. This low TPR indicated that a good flame and heat block fabric also requires high-temperature-resistant insulation of adequate thickness. Assembly 34 (Figure 17) showed that a 4-ounce Nomex batt would not be acceptable insulation, because it exhibited a TPR of only 4.5 and a continued rise in temperature through the instantaneous burn line in about 12 seconds.

Although Assembly 22 (Figure 9) uses a fairly comfortable, lightweight, high-temperature-resistant flame-and-heat block fabric and adequate Kynol batt insulation, it shows a fairly low TPR of 7 and a steep residual rise in temperature towards instantaneous burn. Assembly 22 illustrates the need of a flame-and-heat block fabric that is significantly greater in weight than 8 ounces per square yard.

Table IV. Temperature Rise as Measured from Behind the Fabric Assemblies by "Skin Simulant After Ignition of Pyrotechnic Material in Open Air Testing

Test Code	5 sec Exposure (1) (°C)	TPR (2)	10 Sec Expos. (°C)	15 Expo. (°C)	25 sec Expos. (°C)	35 sec Expos. (°C)
38	2.2	22.0	5.0	8.3	12.2	13.3
22	5.0	7.0	21.1	35.6	42.2	41.1
36	5.0	15.0	7.8	[illegible]	15.0	15.0
24	7.2	>35	10.0	10.1	11.1	10.1
28	7.2	>35	8.3	8.3	10.6	10.6
31	8.3	8.0	12.8	14.4	18.[illegible]	23.3
34	11.1	4.5	32.2	52.8	60.6	53.3
38	13.9	4.0	8.9	6.1	3.8	3.9
39	13.9	4.0	12.8	9.4	7.2	7.2
40	13.9	4.0	8.9	8.9	7.2	7.2
35	15.0	3.8	19.4	19.4	16.1	13.9
37	29.3	1.5	56.7	54.4	48.3	42.2
16	58.9	0.8	141.1	117.8	92.8	78.9
29	75.0	0.6	114.4	97.2	80.0	70.6
25	106.1	0.5	126.1	106.1	85.0	68.9

(1) Approximate exhaustion time of ignited material.

(2) Thermal protective rate (TPR) - Point at which time-temperature curve exceeds the threshold of pain, 111°F.

Table V. Visual Observations of Fabric Assemblies After Exposure to "Flash-Off" of Pyrotechnic Materials

Test Code	Visual Observations
38.	The leather was destroyed and continued to show an after glow until physically extinguished; the insulation and lining showed moderate charring (TPR-22.0).
22.	All three layers of materials were destroyed (TPR-7.0).
36.	Surface of outershell fabric charred, but stayed intact. Surface charring of insulation and slight discoloration of lining occurred (TPR-15.0).
24.	Outershell fabric showed charring and minor holes caused by expelled flaming material. Insulation showed slight charring to the surface facing the heat, while lining material was unaffected (TPR-Infinity).
28.	The outershell fabric showed charring and minor burn-through. The insulation showed a burn-through of about a 6-square-inch area and there was discoloration of the lining (TPR-Infinity).
31.	Outershell fabric was destroyed. Insulation showed a 1-1/2 foot char area over its length with a small burn-through area. The lining fabric was tender and showed shrinkage (TPR - 8.0)
34.	Outershell showed deep char insulation and lining materials were destroyed (TPR-4.5).
38.	The clear outer flexible plastic film melted away leaving the facepiece support untouched. Visibility through facepiece support was fairly good (TPR-4.0).
39.	The gold-coated outer flexible polyester film with the gold coating facing in melted onto the facepiece support, reducing visibility to a minimum (TPR - 4.0).
40.	Same as No. 39 with gold coating on plastic film facing out (TPR-4.0).
35.	Outershell showed charring and minor char holes. Insulation was destroyed and minor discolorations of lining fabric occurred (TPR-3.8).
37.	Outershell fabric was charred and insulation and lining materials were destroyed (TPR-1.5).
16.	Outershell fabric was badly charred and lining fabric was destroyed (TPR-0.8).
29.	Outershell fabric, insulation liner, and lining fabric were destroyed (TPR-0.6).
25.	Material assembly was completely destroyed (TPR-0.5).

Assembly 31 (Figure 12) had the same outershell fabric as assembly 22, but it used a Kevlar felt in place of the Kynol felt. Once again, the TPR for assembly 31 is about equal to that for assembly 22 but with a longer time to reach instantaneous burn. Both fabric assemblies, however, would be considered unacceptable. Assembly 38 (Figure 15), with a gray leather outershell, illustrates the effect of ablation on reducing the temperature rise behind a material assembly. The leather was completely destroyed, but the TPR of 22 was fairly high and only rose slightly above the threshold of pain line after 35 seconds.

Assemblies 24 and 28 (Figures 10 and 13, respectively) showed a TPR greater than 35 seconds. Because the temperature rise for both assemblies did not go above the threshold of pain line, these assemblies would be considered acceptable candidates for use in experimental prototype garments. In both cases the outershell heat block fabric was a 16-ounce PBI/OPF fabric. Assembly 24 used a Kynol felt insulation, and assembly 28 used a 7-ounce Nomex felt insulation. The outershell PBI/OPF fabric for both assemblies 24 and 28 showed charring and minor holes caused by flaming material. However, the fabric kept its shape and retained some strength. The Nomex insulation batt of assembly 28 showed a burn area of over 6 square inches and some discoloration of the lining fabric. The Kynol felt insulation in assembly 24 showed slight charring of the outer surface and no change to the lining fabric.

The plastic faceshield of the hood showed good resistance to the heat after direct exposure to a pyrotechnic composition "flash-off." The clear plastic and the two gold-coated, 7-mil mylar films melted and stuck to the clear acrylic plastic facepiece support. However, the acrylic facepiece support retained its semi-rounded shape and was not distorted by the heat. Although it was difficult to see through the plastic faceshield because of the melting and charring of the outer layer of polyester film, the recorded temperature showed a relatively small increase of about 114.8 degrees F (13.5 degrees C) in 5 seconds and a rapid drop in temperature upon exhaustion of the illuminant composition (Figure 20). It is important to note that the pyrotechnic processing personnel will be required to wear a facemask with the hood, a practice which should help to keep the plastic faceshield an acceptable distance from the forehead.

Heat Testing Experimental Prototype Garments

Based on the results from the preliminary test and evaluation of the candidate fabric assemblies, two combinations were chosen to be made into coveralls and tested at the open air site, under the same conditions as the fabric sleeves. The fabric assembly chosen for each of the garments contained the following material combinations: a 16-ounce OPF fabric/10-ounce Kevlar batt/5.5-ounce FR cotton fabric laminated to an expanded PTFE plastic film; and a 15.5-ounce PBI/OPF fabric/10-ounce Kevlar batt/5.5-ounce FR cotton fabric laminated to PTFE film. The two types of prototype coveralls were placed on manikins containing "skin simulants" on the forehead, the right and left chest area, and both arms. The manikins were dressed in cotton underwear and a fire-resistant-treated, 8 oz/yd^2, cotton fabric coverall before they were dressed in the experimental coveralls. A hood made from the same combination of fabric as the experimental pyrotechnic coveralls was made part of the test ensemble. The plastic faceshield for both ensembles contained a clear-plastic-acrylic, 1/8-inch-thick facepiece support. Placed over the outside of the facepiece support were two 15-mil, clear-plastic polycarbonate films.

Plastic Faceshields After Flash-off

During ignition of the 15 pounds of pyrotechnic composition, the plastic faceshields were observed on the video camera, and it was noted that the polycarbonate films that made up the outer layers of the faceshield melted and dripped away from the facepiece support. The ablative melting of the films helped reduce the heat reaching the acrylic 1/8-inch-thick plastic facepiece support to a degree that it was not distorted by the heat and continued to afford a fair degree of visibility. Data from the first of two "flash-offs" showed that the "skin simulant" positioned in the forehead of the manikin wearing the OPF hood and facemask registered a temperature rise of 25 degrees F. The manikin with the PBI/OPF fabric hood and no facemask registered a temperature rise of 57 degrees F, but at 6 and 40 seconds after the start of the "flash-off," the recorded temperatures dropped to 17 and 25 degrees F, respectively. Assuming the temperature of human skin to be 91.5 degrees F, the total temperature rise should be from 116.5 degrees F to 148.5 degrees F during the first 6 seconds and at 104.5 degrees F and 118.5 degrees F 19 seconds after the start of the "flash-off." The 148.5 degrees F reading appears to have been caused by the head of the manikin falling forward towards the plastic faceshield. Data from the second "flash-off" was not recorded because of faulty wiring.

Other Sensor Data After Flash-off

The recorded data from other sensors were comparatively low. The "skin simulant" located in the areas that were covered by both the hood and coverall showed a maximum 3 degree F rise. One sensor located in the right forearm of the garment made from the OPF fabric showed a 2 degree F rise at 6 seconds and a maximum temperature rise of 27 degrees F at 19 seconds after the start of the "flash-off." At 65 seconds after the start of the "flash-off," one of the four sensors located in the breast area showed a temperature rise of 8 degrees F, and the right forearm sensor in the OPF fabric rose to 33 degrees F. It should be noted that all the mixing bays are outfitted with a water deluge system that is automatically activated by an infrared sensor directed at the center of the mixing bowl. Certainly, a deluge of water should prevent any continued increase in temperature beyond the initial 5-to-10-second "flash-off."

Experimental Garments After Flash-off

The following general observations can be made for the experimental garments that were exposed to a pyrotechnic illuminant composition "flash-off." The PBI/OPF outershell fabric withstood the "flash-off" of the composition better than the OPF outershell fabric. This could be due to the positioning of the manikins to the "flash-off" as well as to the difference in fabrics. Also, the pyrotechnic composition does not "flash-off" uniformly, making comparisons of the two outershell fabrics difficult, even though they were tested side-by-side. The Kevlar straps used to hold down the hood charred and burnt away along with the Kevlar sewing thread, thus exposing the Kevlar insulation. At the exposed areas, the cotton coveralls showed the start of charring. In all other areas of the coverall and hood, the expanded PTFE-laminated cotton-fabric liner remained unchanged by the "flash-off."

CONCLUSIONS

A large group of flame-resistant fabrics and insulation felts were assembled for the purpose of exposing them in assembly to a pyrotechnic illuminant composition "flash-off." A series of six tests were performed exposing three assemblies in each test to a "flash-off" of 15 pounds of material. Based on the data presented in the report, the following conclusions can be made.

1. A material assembly for use in a pyrotechnic safety garment should contain an outershell fire and heat block fabric, a felt insulation, and a vapor barrier liner.

2. The outershell fabric for use in pyrotechnic safety clothing should weigh about 15.5 ounces per sq. yd., have a minimum thickness of about 40 mils, and afford a degree of comfort when used in garments that are worn over a period of time.

3. The outershell fabric that showed the best resistance to a pyrotechnic material "flash-off" was the PBI-wrapped, semi-carbonized, OPF fabric weighing about 15.5 ounces per sq. yd.

4. The batt insulation must resist melting and char-through in order to keep the temperature rise behind the material assembly below 20 degrees F (11.5 degrees C), which was considered the threshold of pain for human skin.

RECOMMENDATIONS

After close examination of all data discussed in this report, NCTRF recommends the following.

1. Kevlar fiber appears to be well-suited as the insulation batt for the experimental prototype garments.

2. Fire-resistant cotton-base fabric is recommended as a substitute for the 3.2-ounce Nomex base fabric for the vapor barrier liner.

3. The outershell fabric, insulation felt, and vapor barrier liner, described in Appendixes A, B, and C, should be considered in making experimental prototype safety garments for use by pyrotechnic processing personnel. The requirements in Appendixes A, B, and C can be used to prepare a purchase description for each of the three fabrics.

4. The Kevlar hold-down straps for the hood should be replaced with a PBI webbing, and PBI sewing thread should also be considered as a replacement for the Kevlar sewing thread.

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APPENDIX A.
CLOTH, FLAME- AND HEAT-RESISTANT

Fibers. The fiber used for the wrapping portion of the finished yarn shall be polybenzimidazole (PBI), natural in color (tan). The core of the finished yarn shall be oxidized polyacrylonitrile (OPF). The resulting color shall be natural (black).

Yarn. The OPF (core) yarn shall be a 10 single worsted count made from high density (1.4 g/cm^3), high tenacity (1.7 grams per denier), partially oxidized polyacrylonitrile fiber. The yarns for both warp and filling shall be of 1/10 worsted-count OPF yarn made by wrapping a PBI yarn around the core yarn and the resulting yarn 2-plied. (See Table VI.)

Finished Fabric. The finished fabric shall be woven with a 2/2 herringbone twill, repeating on 15 ends.

TABLE VI. FABRIC REQUIREMENTS

Characteristics	Requirements	
	MIN	MAX
Weight (oz/yd^2)	14.5	17.5
Yarns per Inch		
Warp	29.0	33.0
Filling	19.0	23.0
Breaking Strength (lbs.)		
Warp	155.0	
Filling	115.0	

Testing of Finished Fabric. The method of testing specified in FED STD 191, wherever applicable, and listed in Table VII shall be followed.

TABLE VII. TEST METHODS FOR FINISHED FABRIC

Characteristics	Requirement Paragraphs	Test Methods
Weight	Table I	5041
Yarns per Inch	Table I	5050
Breaking Strength	Table I	5100
Tear Strength	Table I	5132
Air Permeability	Table I	5450
Shrinkage	Table I	5556(1)
Thickness	Table I	5030(2)
Flammability	Table I	5903
Fiber Content	Table I	(3)
Weave	3.3.2.1	Visual

(1) Cotton mobile laundering.
(2) Para 4.1.1 of TM5030, 0.6 PSI ± .03 PSI; diameter of pressure foot, 1.129 inches.
(3) The contractor shall furnish a certificate of compliance for this characteristic.

APPENDIX B.
BATTING, PARA-ARAMID (KEVLAR)

Aramid Fiber Staple. The cut staple fibers used in the batting shall be high-strength, medium modulus aramid with a minimum fiber tenacity of 20 grams per denier. The filament shall have a linear density of 1.5 denier per filament. The fibers shall have a nominal length of 2 inches. The color (yellow) shall be that as produced by the manufacturer. Bleach or color modifiers shall not be used.

Scrim. The scrim used in the construction of the finished batting shall be made of polyester and weigh a minimum of 1.8 ounces per sq yd.

Batting (unsupported). The unsupported batting shall be made from fiber as specified. The batting shall be needled with about 240 penetrations per inch (PPI) of width. The batting shall weigh about 2.56 $\pm$ 0.26 ounces per sq yd.

Finished Batting. The finished batting shall be constructed of one layer of scrim positioned between one layer of batting on one side and two layers of batting on the other side. The scrim and the layers of batting shall be needled together with about 210 penetrations per inch of width. (See Table VIII.)

Evenness of Batting. The evenness of the finished batting shall be to the degree that no single determination shall deviate more than 0.6 oz per sq yd from the mean of five specimens.

TABLE VIII. REQUIREMENTS FOR FINISHED BATTING

Characteristics	Requirements MIN	Requirements MAX
Weight (oz/yd^2)	9.3	11.3
Thickness	0.34	0.42
Compression Recovery	80	-
Tear Strength (lbs.)		
Warp	30	
Filling	25	
Air Permeability (ft^3/min/ft^2)		35
Shrinkage (%)		
Warp		6.5
Filling		3.0
Thickness (in)	0.040	-
Flammability Resistance		
After Flame (sec)		1
After Glow (sec)		5
Char Length (in)		1
Fiber Content (%)		
PBI	18	24
OPF	76	82

Testing of Finished Batting. The methods of testing specified in FED STD 191, wherever applicable, and listed in Table IX shall be followed.

TABLE IX. TEST METHODS FOR FINISHED BATTING

Characteristics	Requirement Para.	Test Methods	Results Reported As
Scrim			
Material Identification	3.3.2	(1)	
Weight (oz/yd^2)	3.3.2	5041	Avg. of 5 specimens
Batting (unsupported)			
Material Identification	3.3.1 & 3.3.3	(1)	
Weight (oz/yd^2)	3.3.3	5041	Avg. of 5 specimens
Batting (finished)			
Weight (oz/yd^2)	Table I	5041(2)	Avg. of 5 specimens
Thickness	Table I	4.5.1(2)	Nearest .01 inch
Compression Recovery (%)	Table I	4.5.2(2)	Nearest 1%
Evenness of Batting	3.3.4.1	5041(3)	

(1) A certificate of compliance is acceptable for this requirement.
(2) Test specimens shall be allowed to relax on a flat surface without pressure for a minimum of 24 hours at standard conditions prior to testing.
(3) Test shall be determined using 8 x 8 inch specimens.

Editor's Note: The following paragraphs also pertain to Table IX.

4.5.1 Determination of Thickness. Thickness of the batting shall be determined in accordance with the method specified in 4.5.2.3 for "initial thickness of specimen."

4.5.2 Determination of Compressional Recovery.

4.5.2.1 Preparation of Specimen. The specimen shall be cut from different parts of a full-width sample and shall measure not less than 6 inches by 6 inches. The specimen shall always be larger than the pressure foot on the test apparatus.

4.5.2.2 Apparatus. The test apparatus shall have a means of applying 0.01 and 5.0 lbs per sq in loading on the specimen. This pressure shall be evenly distributed over the 20 sq in area. The base plate shall have a diameter not less than 5.0 inches. The circular pressure plate shall have a bearing surface of 20 sq in.

4.5.2.3 Procedure. Apply 0.01 lb per sq in pressure to the test specimen and maintain for 10 seconds. The thickness reading shall then be taken and recorded as "initial thickness" (see 4.5.1). Immediately after determining the initial thickness, the pressure shall be increased to 5 lbs per sq in and maintained for 1 minute. The pressure shall then be completely removed, and the specimen shall be allowed to relax for 5 minutes. Immediately after the 5-min relaxation period, the thickness of the specimen shall again be determined under the initial lbs per sq in pressure and be recorded as the "thickness of the specimen after compression."

4.5.2.4 Calculation of Results. The percent of compressional recovery shall be determined by the following formula:

$$\%\text{ of compressional recovery} = \frac{\text{Thickness of specimen after compression}}{\text{Initial thickness of specimen}} \times 100$$

The percent of compressional recovery shall be determined from five specimens, and the results averaged and recorded to the nearest 1 %.

APPENDIX C.
CLOTH, COTTON, LAMINATE, FIRE-RESISTANT

Base Fabric. The base fabric shall be 100% cotton made with single yarn in the warp and filling. The color shall be natural.

Weave. The weave shall be a modified basket weave, with two ends weaving as one and two picks weaving as one.

TABLE X. BASE FABRIC REQUIREMENTS

Characteristics	Requirements	
Characteristics	MIN	MAX
Weight (oz/yd^2)	5.5	6.5
Yarns per Inch		
Warp	94	-
Filling	72	-
Breaking Strength (lbs.)		
Warp	75	-
Filling	45	-
Tear Strength (lbs.)		
Warp	5.0	-
Filling	5.0	-
Flammability Resistance, Warp and Filling		
After Flame (sec)	-	5
After Glow (sec)	-	5
Char Length (in)	-	6

Laminated Cloth. The basic fabric shall be laminated to the plastic film. The face of the laminated cloth shall be the fabric side. The laminated cloth shall conform to the requirements of Table XI, when tested as specified in Table XII.

TABLE XI. LAMINATED CLOTH REQUIREMENTS

Characteristics	Requirements	
	MIN	MAX
Weight (oz/yd^2)	6.0	7.0
Breaking Strength (lbs.)		
Warp	82	-
Filling	64	-
Tear Strength (lbs.)		
Warp	4.0	-
Filling	4.0	-
Hydrostatic Resistance (PSI)		
Initial	100	-
After Strength of Coating	100	-
After High Humidity	100	-
Stiffness (cm)		
Warp	-	12.0
Filling	-	8.5
Resistance to Leakage		No Leakage
MVTR (g/m^2/24 hrs)	550	-
Flame Resistance, Warp & Filling		
After Flame (sec)	-	2.0
After Glow (sec)	-	8.0
Char Length (in)	-	5.0

TABLE XII. TEST METHODS FOR LAMINATED CLOTH

Characteristics	Requirement Para.	Test Methods
Weight	Table I & II	5041
Breaking Strength	Table I & II	5100+5102
Tearing Strength	Table I & II	5132
Yarns per Inch	Table I	5050
Flame Resistance	Table I & II	5903
Resistance to Leakage	Table II	5516(1)
MVTR	Table II	7032 Method B(2)
Stiffness	Table II	5204
Hydrostatic Resistance	Table II	
Initial		5512(3)
After Strength of Coating		5972(4) +5512 (3)
After High Humidity		5512(5)

(1) Except that the face side of the laminated cloth shall contact the water. The hydrostatic head shall be 50 centimeters and shall be held for 10 minutes. The report shall include only measurement of the appearance of water drops.

(2) Method of testing specified in FED STD 406, 5 Oct 1961. The coated side of the laminated fabric shall face the water.

(3) The water pressure shall be applied to the coated side of the laminated fabric.

(4) E·cept that the specimen shall be stretched at 20 pounds.

(5) ee 4-by-4-inch specimens shall be laid flat, face side up, on a supporting plate and the as· bly placed in a desiccator containing water in the lower portion. The water level shall be about 1 inch below the specimens. The lid of the desiccator shall be put in place and the desiccator placed in a circulating air oven having a temperaure of 160 degrees ± 2 degrees F for a period of 7 days. At the end of the aging period, each specimen shall be removed f· om the desiccator and tested immediately in accordance with Method 5512 of FED STD ·91 with the water pressure being applied to the face side.

APPENDIX D. ILLUSTRATIONS

Figure 1. "Flash-off" of 15 lbs of pyrotechnic materials at open-air experimental test site.

Figure 2. Assembly No. 23: Outershell, 99% Wool/1% steel fiber, 7 oz/yd^2; Insulation Liner, Kynol batting, 6.5 oz/yd^2; Moisture Barrier Liner, PTFE/Nomex, 3.6 oz/yd^2.

Figure 3. Assembly No. 30: Outershell, 80% PFR Rayon/ 20% Nomex, 7 oz/yd^2; Insulation Liner, Nomex batt, 6.9 oz/yd^2; Moisture Barrier Liner, PTFE/ Nomex, 3.6 oz/yd^2.

Figure 4. Assembly No. 25: Outershell, PBI, 8.1 oz/yd^2;
Insulation Liner, 65% PFR Rayon/35% wool batting;
Moisture Barrier Liner, PTFE/Nomex, 3.6 oz/yd^2.

Figure 5. Assembly No. 31: Outershell, PBI, 9.1 oz/yd^2;
Insulation Liner, Kevlar batting, 8.4 oz/yd^2;
Moisture Barrier Liner, PTFE/Nomex, 3.6 oz/yd^2.

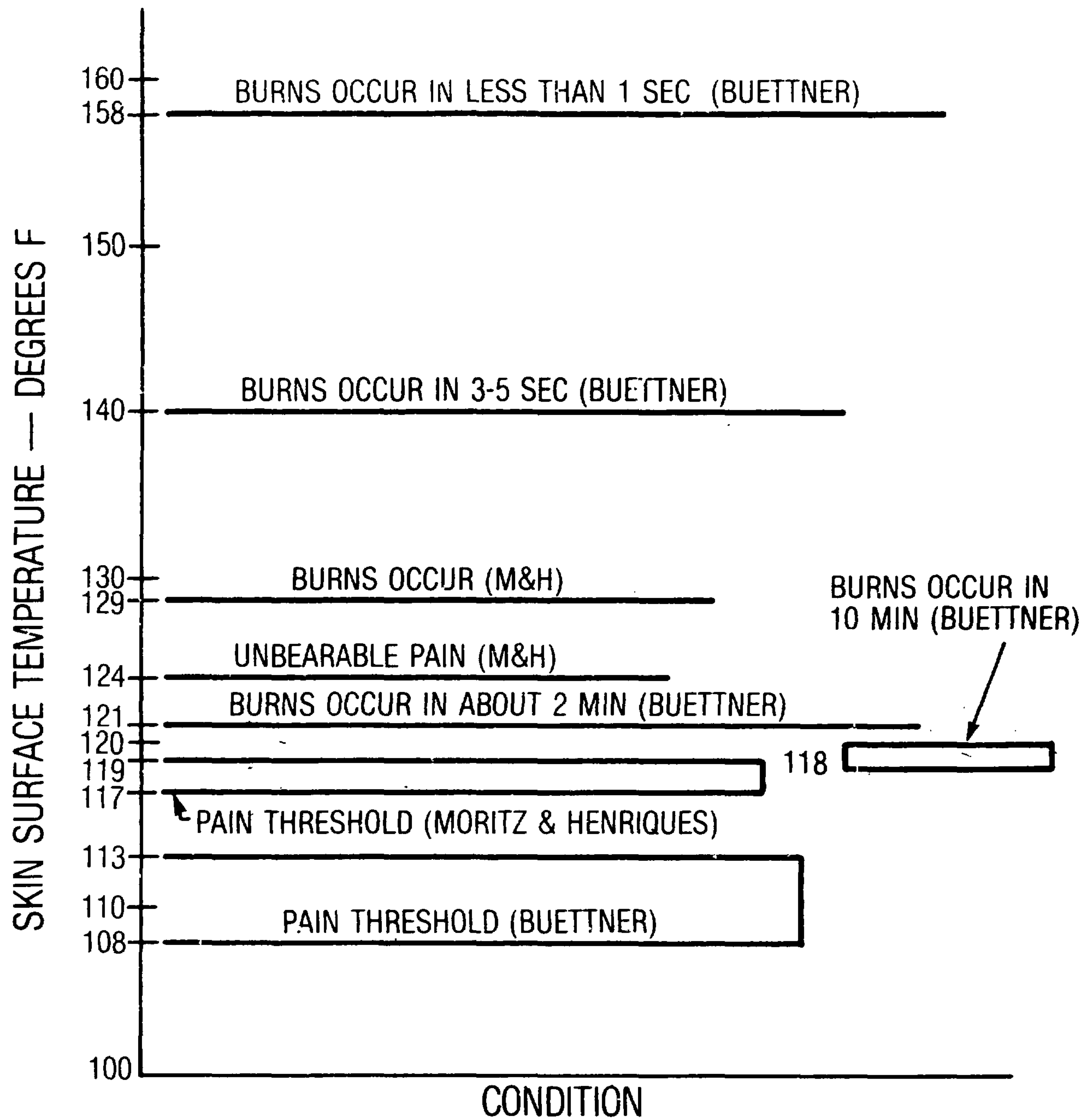

Figure 6. Physiological Effects of Elevated Skin Temperatures.

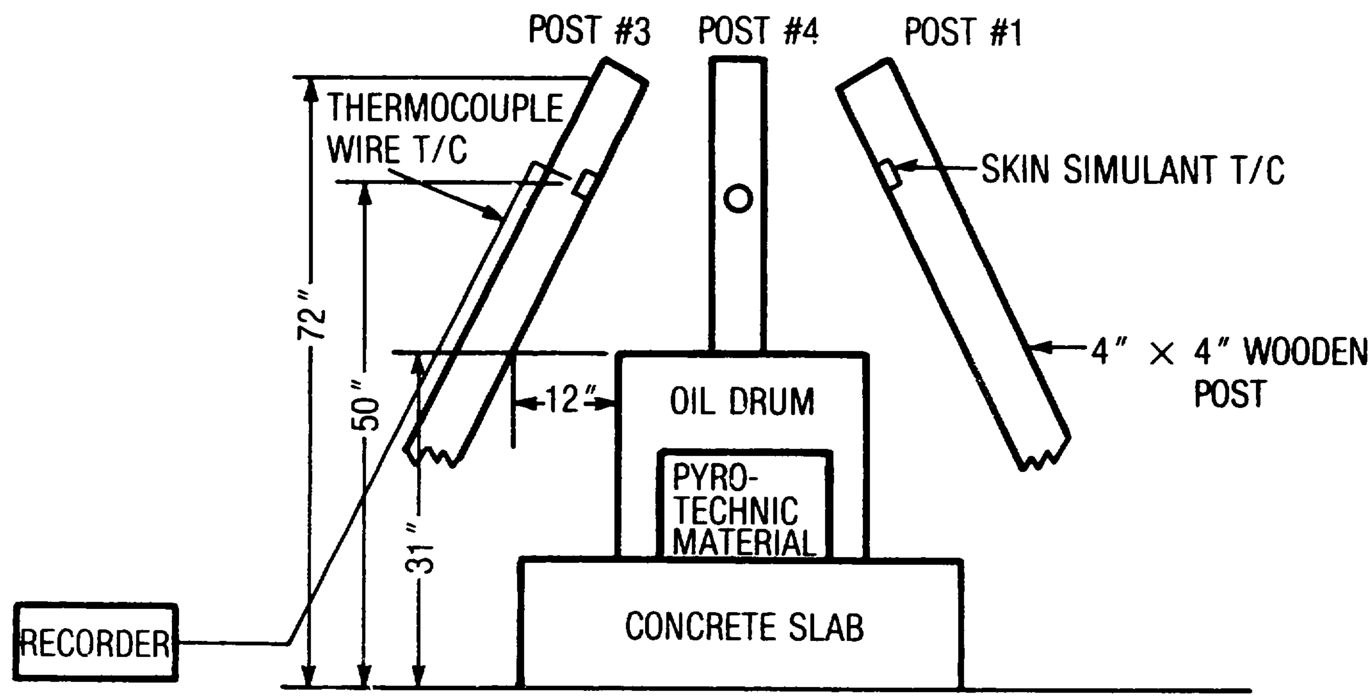

Figure 7. Test Sites Showing Wooden Posts Positioned Around Oil Drum Containing Pyrotechnic Material.

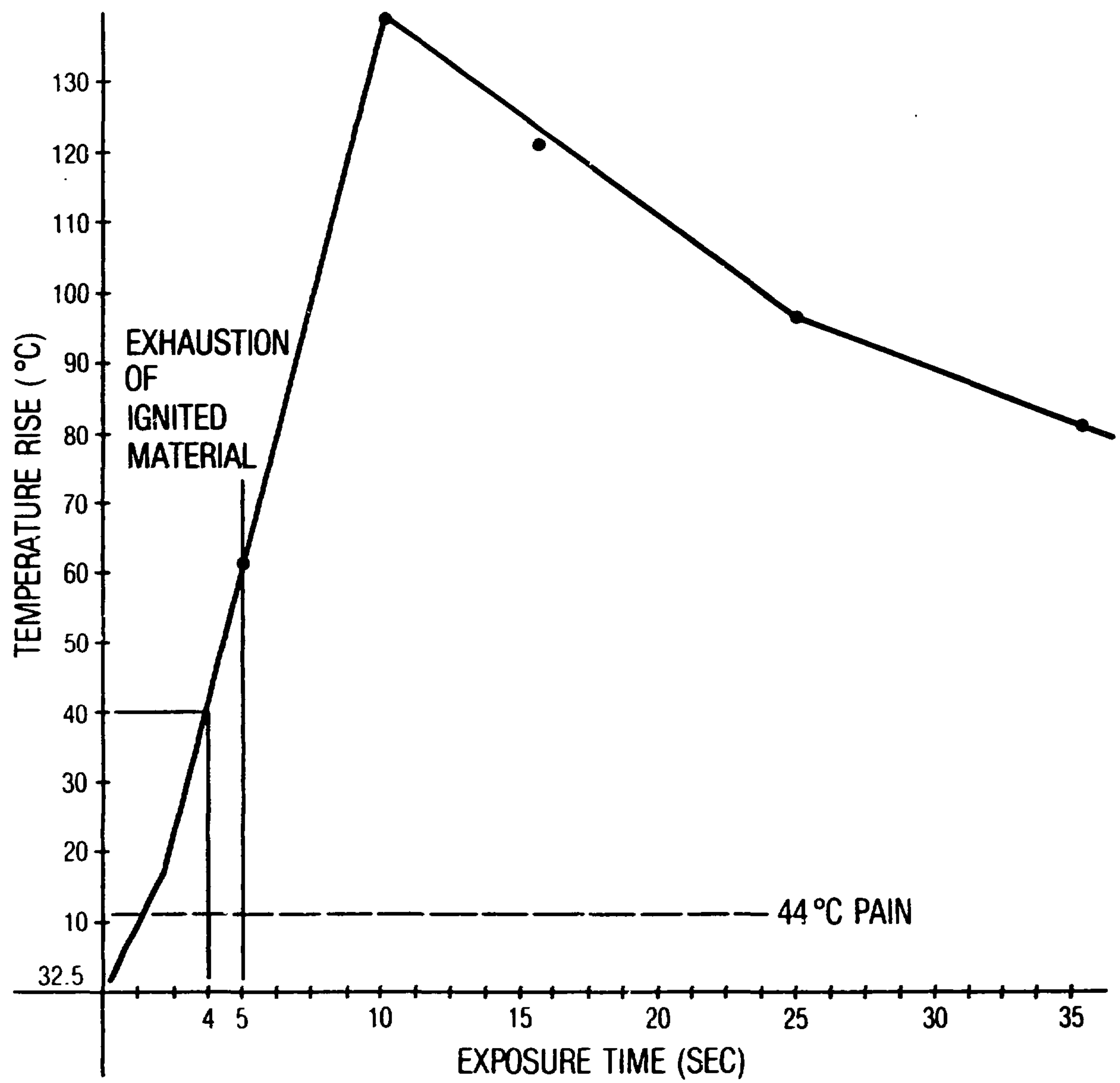

Figure 8. Temperature Rise Above Ambient Temperature With Time as Measured by Skin Simulant, No. 16 PBI, Semi-Carbon Fabric, TPR, 0.8.

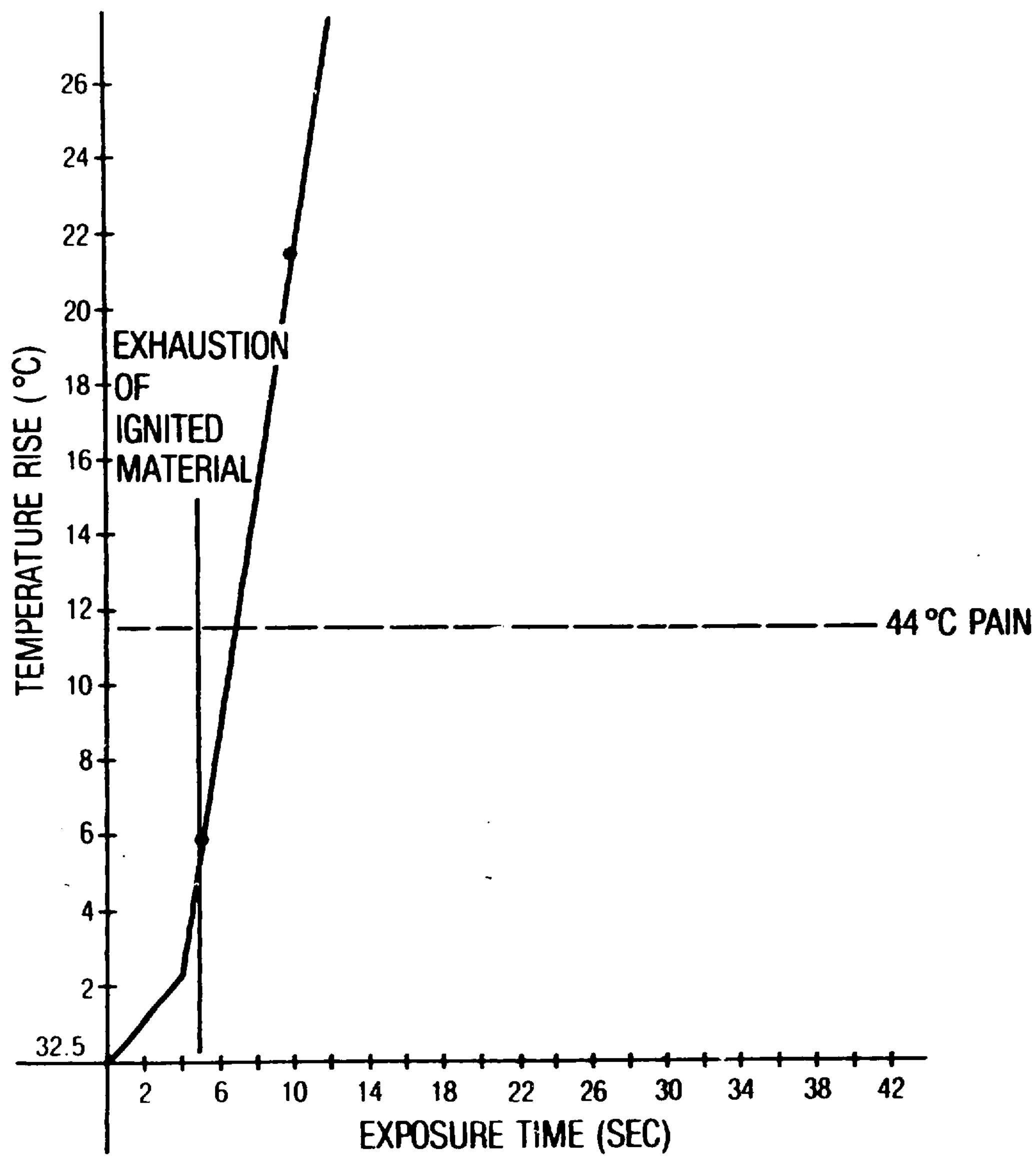

Figure 9. Temperature Rise Above Ambient Temperature With Time as Measured by Skin Simulant, No. 22 Light Brown PBI Fabric/Kynol Felt/PTFE Nomex Fabric, TPR, 7.

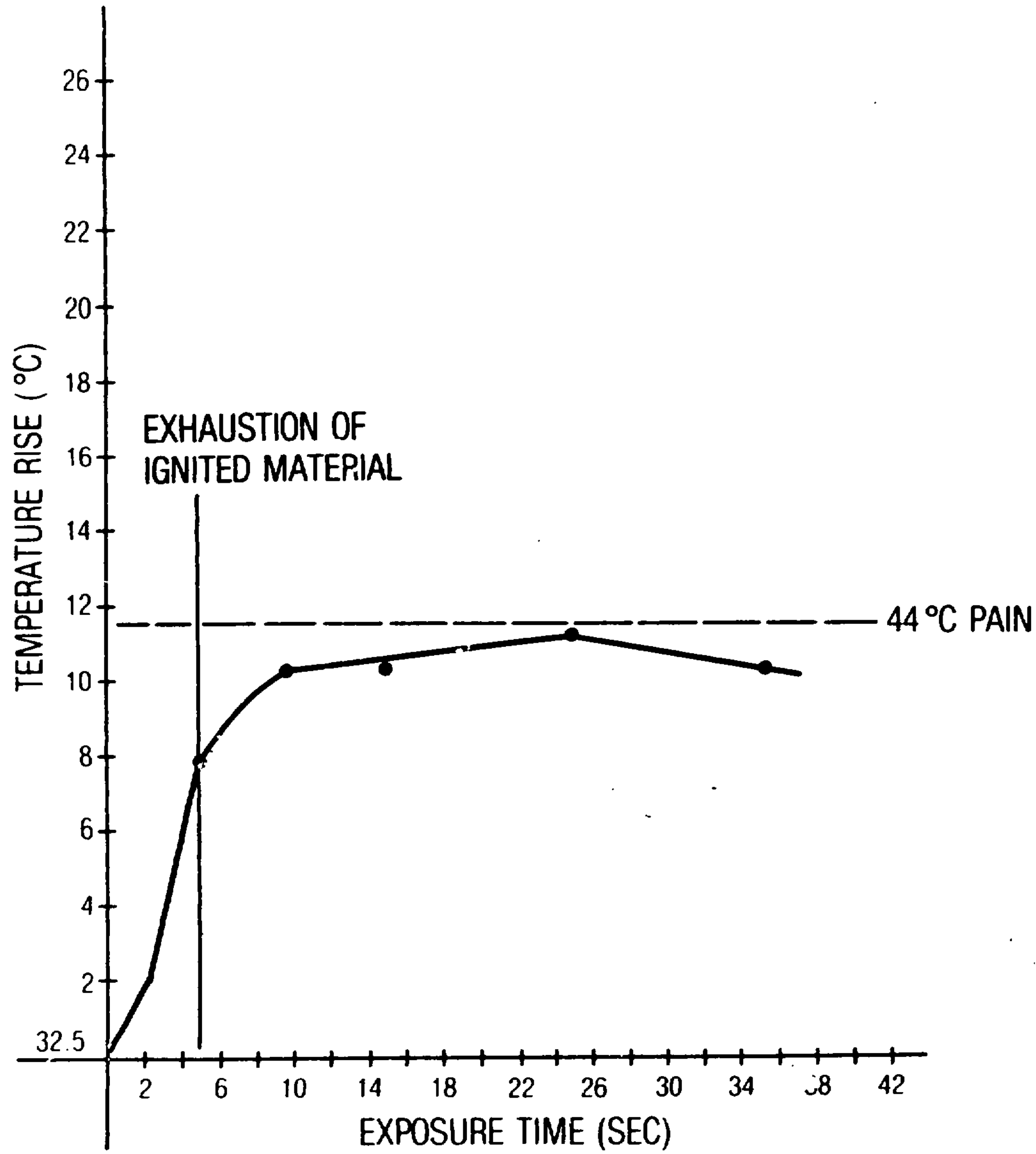

Figure 10. Temperature Rise Above Ambient Temperature With Time as Measured by Skin Simulant, No. 24 PBI, Semi-Carbon Fabric/Kynol Felt/PTFE Nomex Fabric, TPR, more than 35.

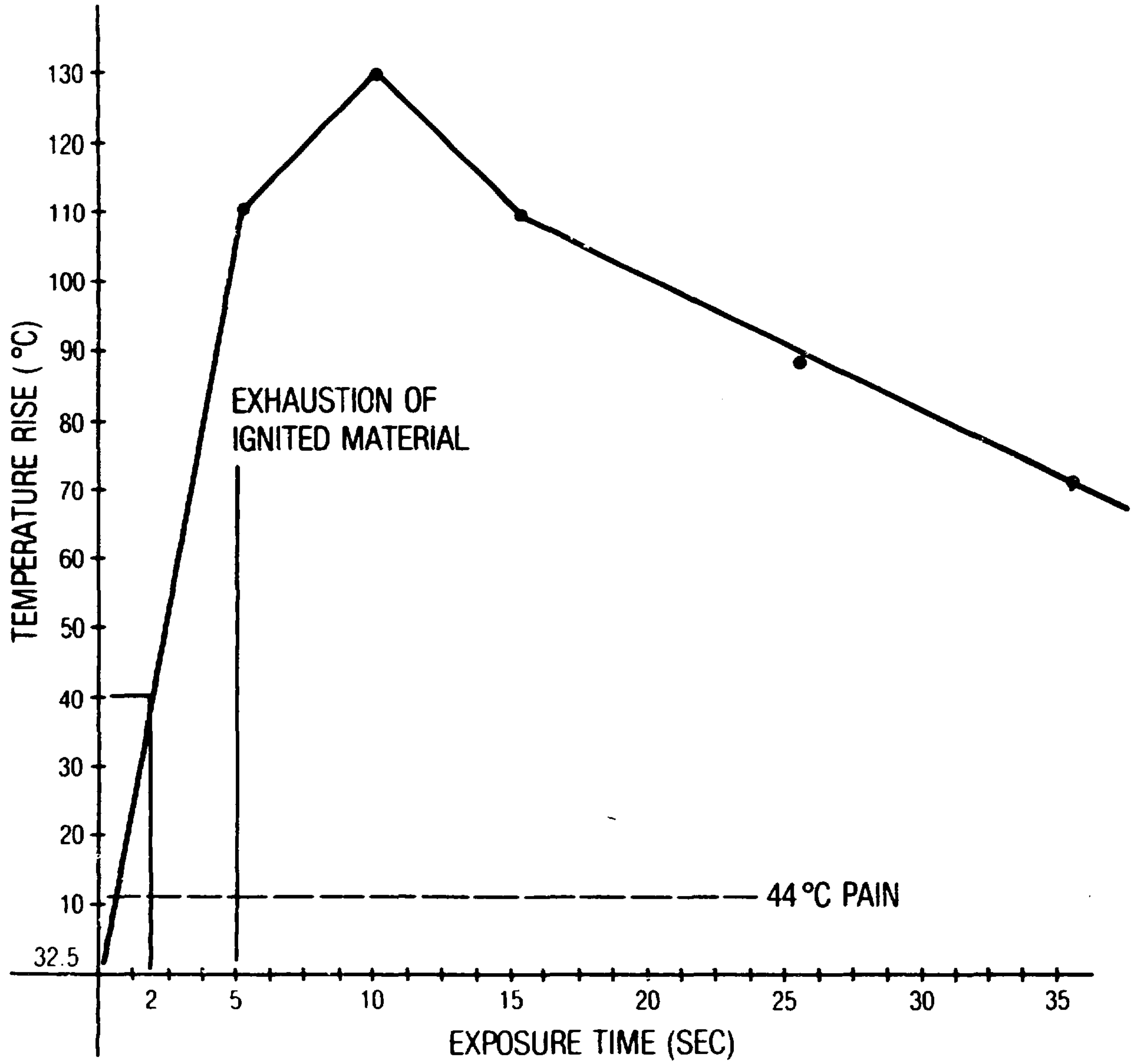

Figure 11. Temperature Rise Above Ambient Temperature With Time as Measured by Skin Simulant, No. 25 Dark Brown PBI Fabric/Rayon-Wool Felt/PTFE Nomex Fabric, TPR, 0.5.

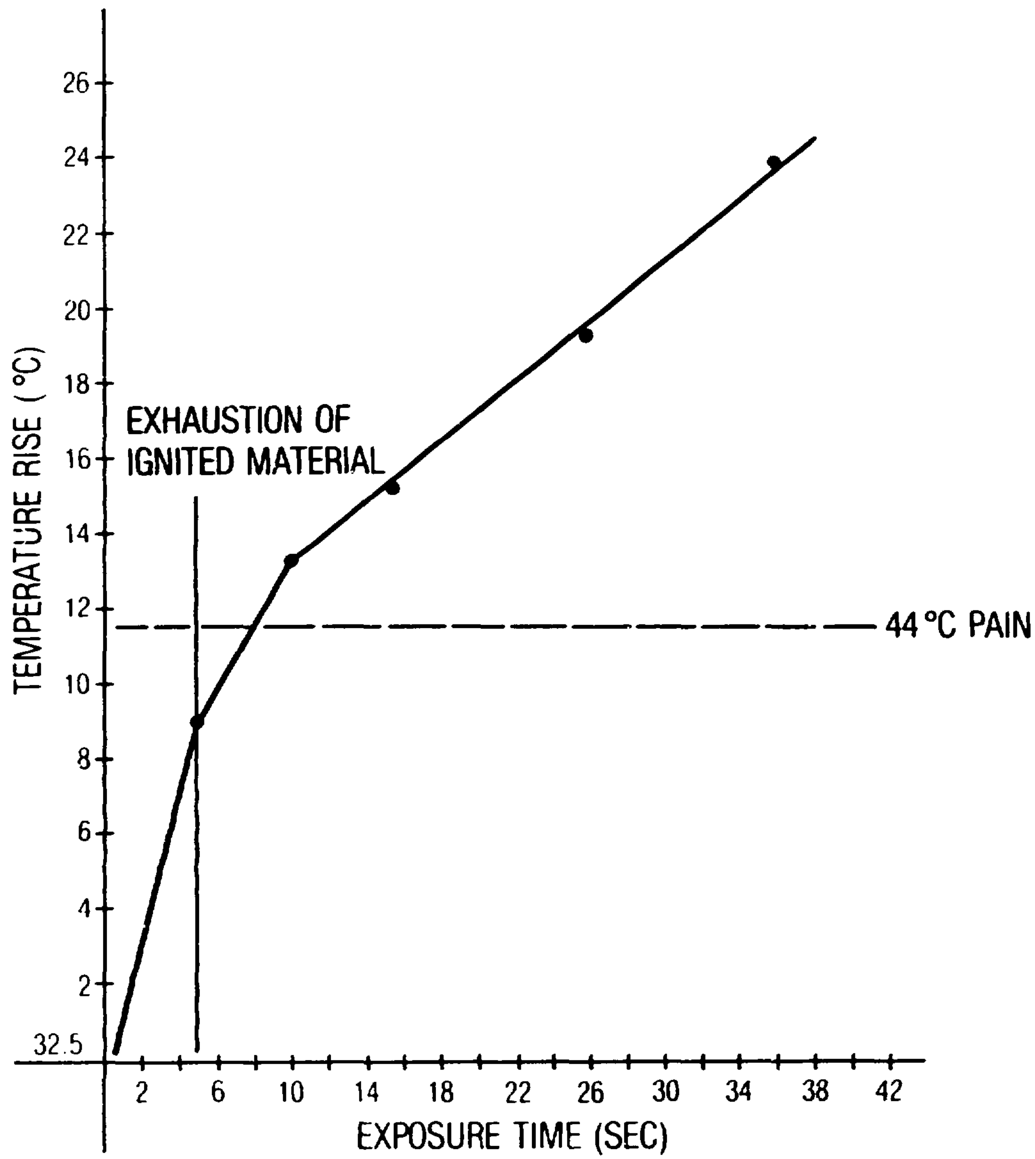

Figure 12. Temperature Rise Above Ambient Temperature With Time as Measured by Skin Simulant, No. 31 Light Brown PBI Fabric/Kevlar Felt/PTFE Nomex Fabric, TPR, 8.

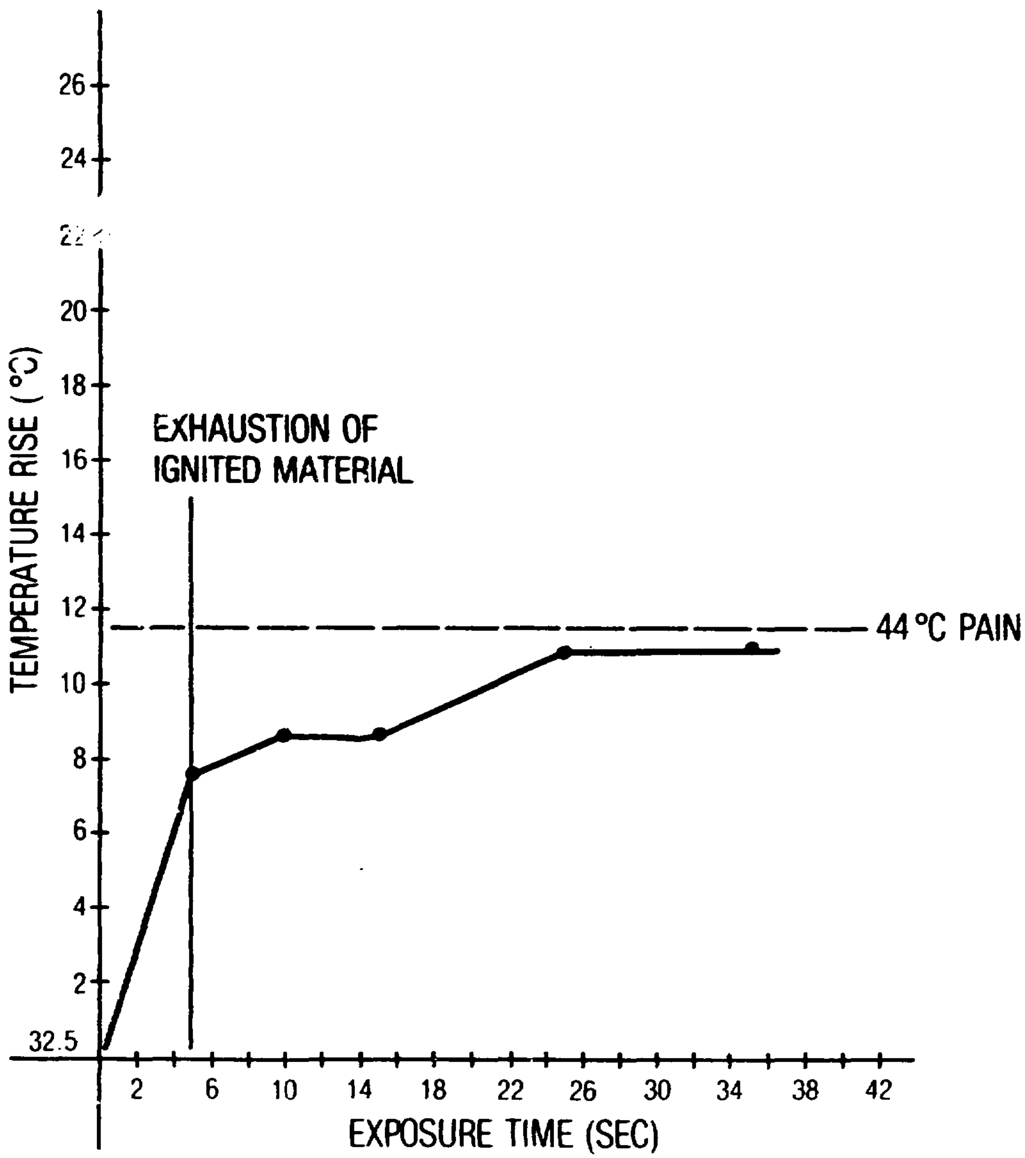

Figure 13. Temperature Rise Above Ambient Temperature With Time as Measured by Skin Simulant, No. 28 PBI, Semi-Carbon Fabric/7 oz Nomex Felt/PTFE Nomex Fabric, TPR, more than 35.

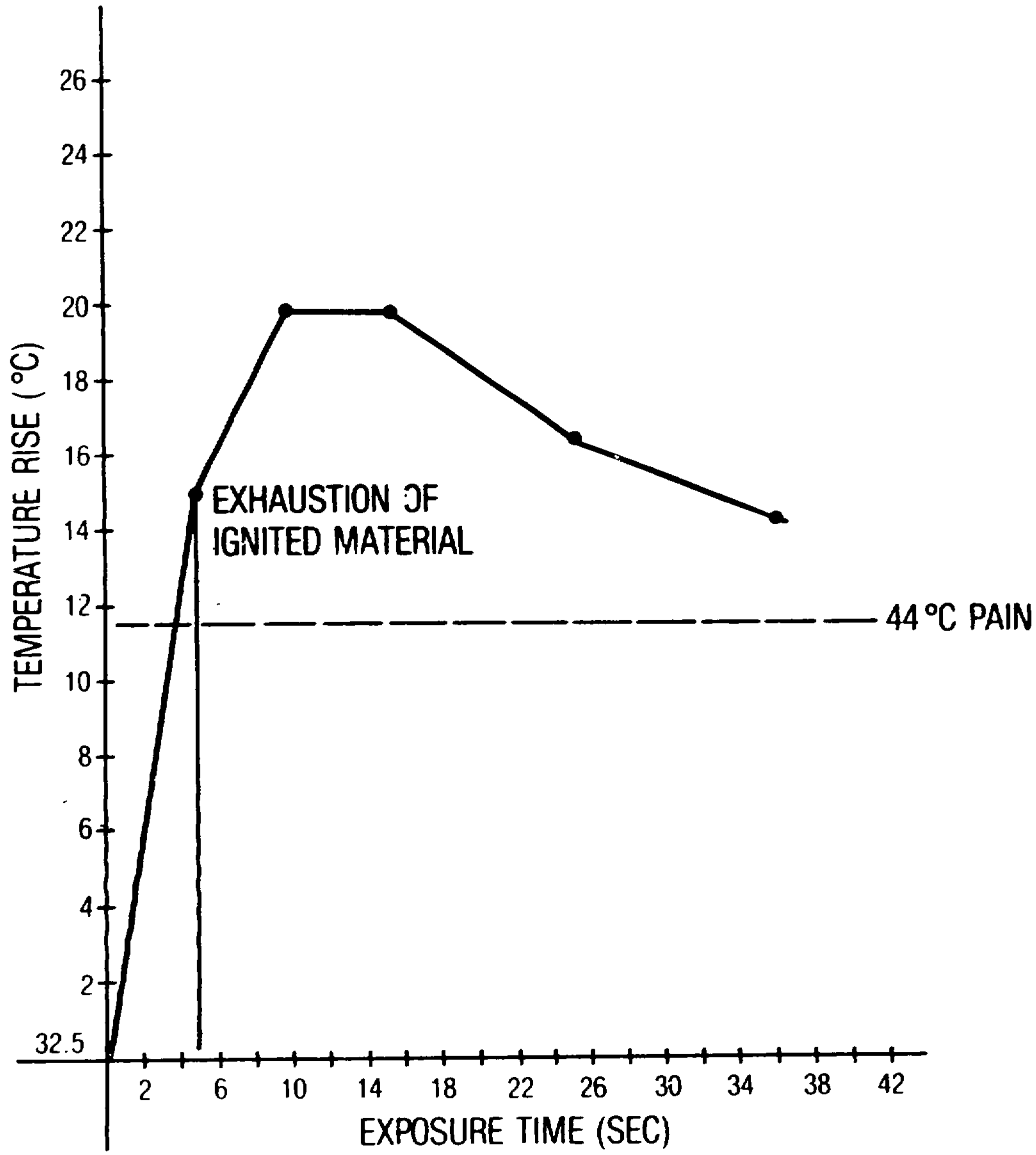

Figure 14. Temperature Rise Above Ambient Temperature With Time as Measured by Skin Simulant, No. 35 PBI, Semi-Carbon Fabric/Rayon-Wool Felt/PTFE Nomex Fabric, TPR, 3.8.

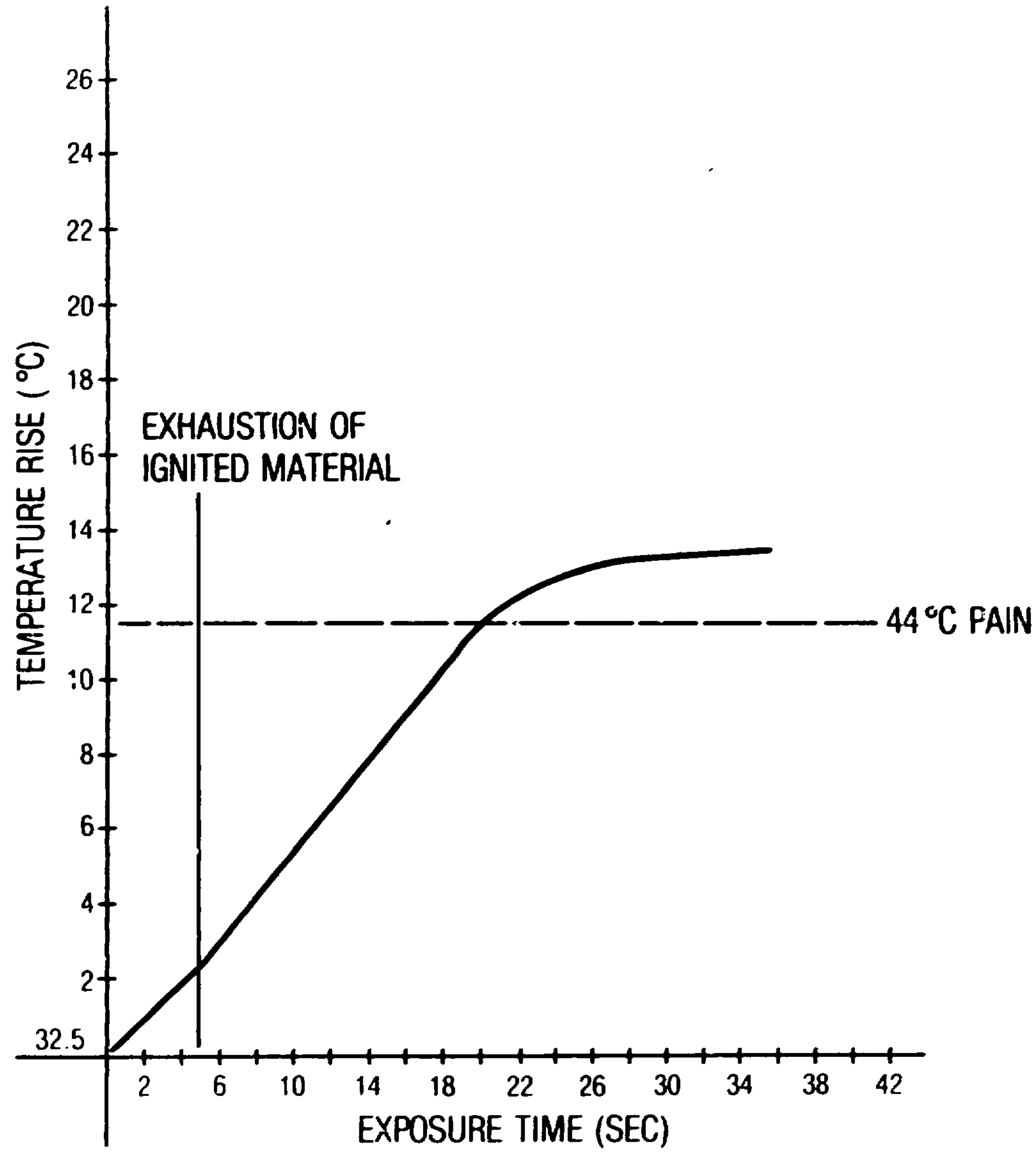

Figure 15. Temperature Ris · Above Ambient Temperature With Time as Measured by Skin Simulant, No. 38 Gray Leather/Kevlar Felt/PTFE Nomex Fabric, TPR, 22.

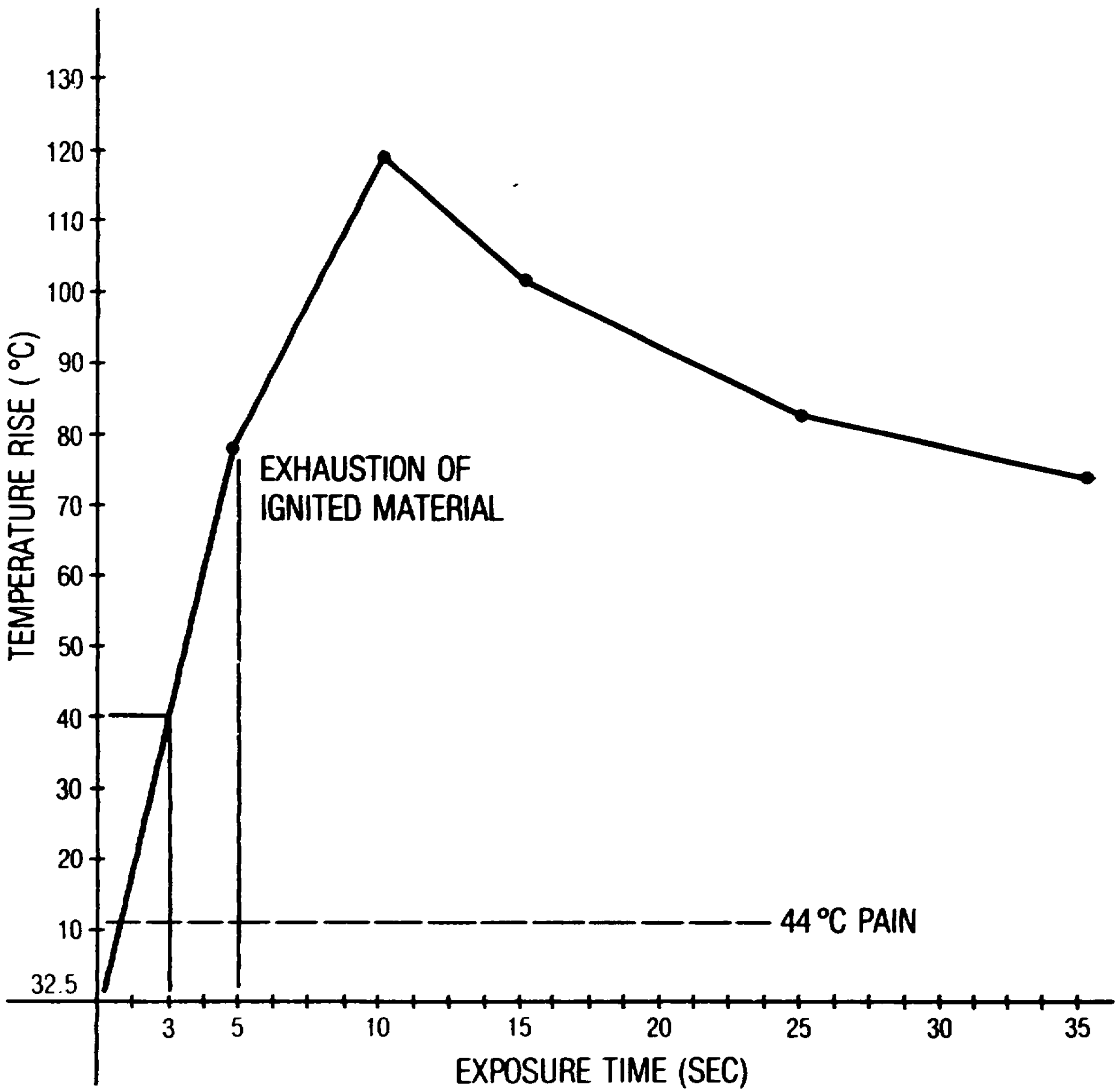

Figure 16. Temperature Rise Above Ambient Temperature With Time as Measured by Skin Simulant, No. 29 Light Brown PBI Fabric/7 oz Nomex Felt/PTFE Nomex Fabric, TPR, 0.6.

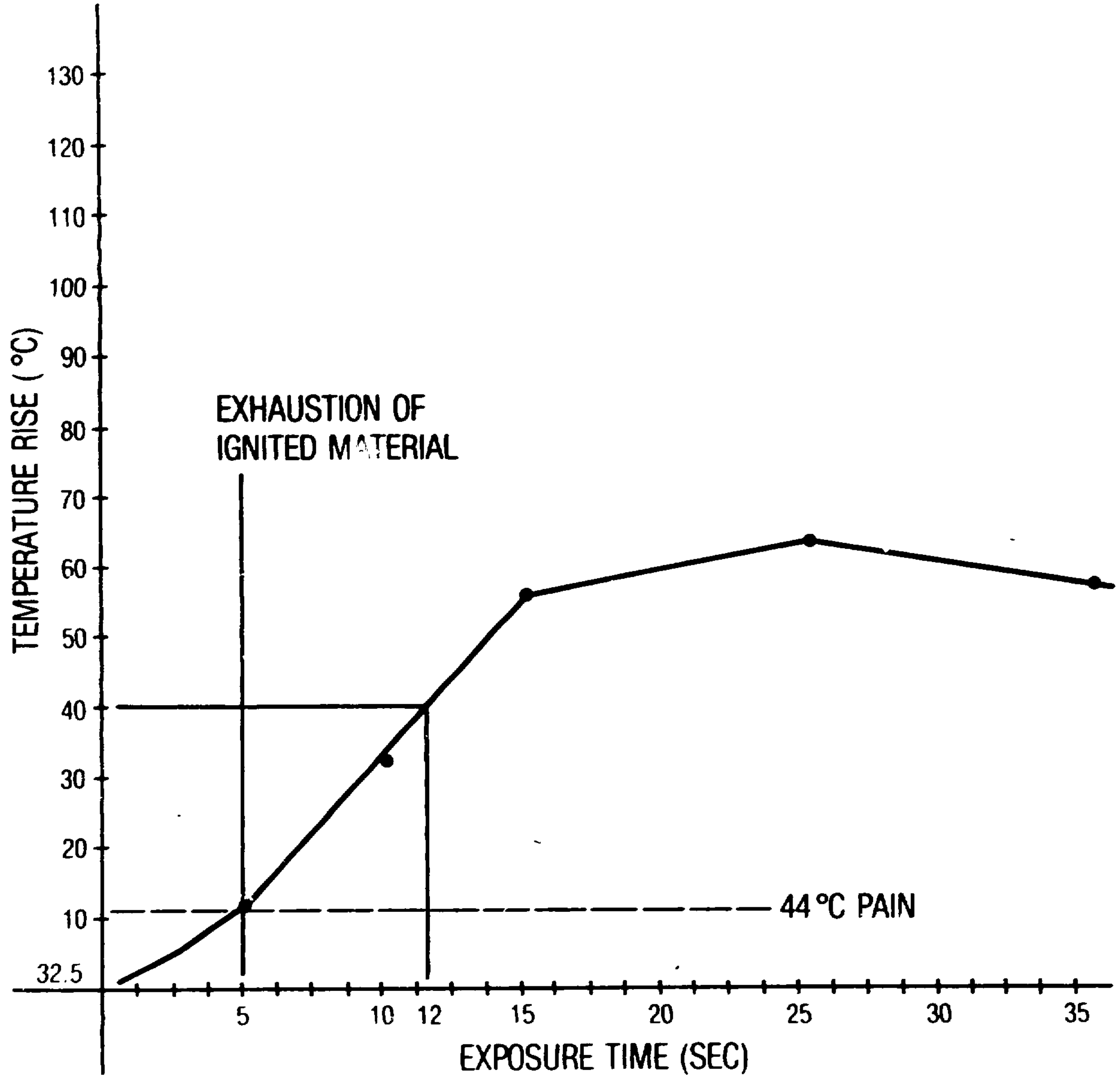

Figure 17. Temperature Rise Above Ambient Temperature With Time as Measured by Skin Simulant, No. 34 PBI, Semi-Carbon Fabric/4 oz Nomex Felt/PTFE Nomex Fabric, TPR, 4.5.

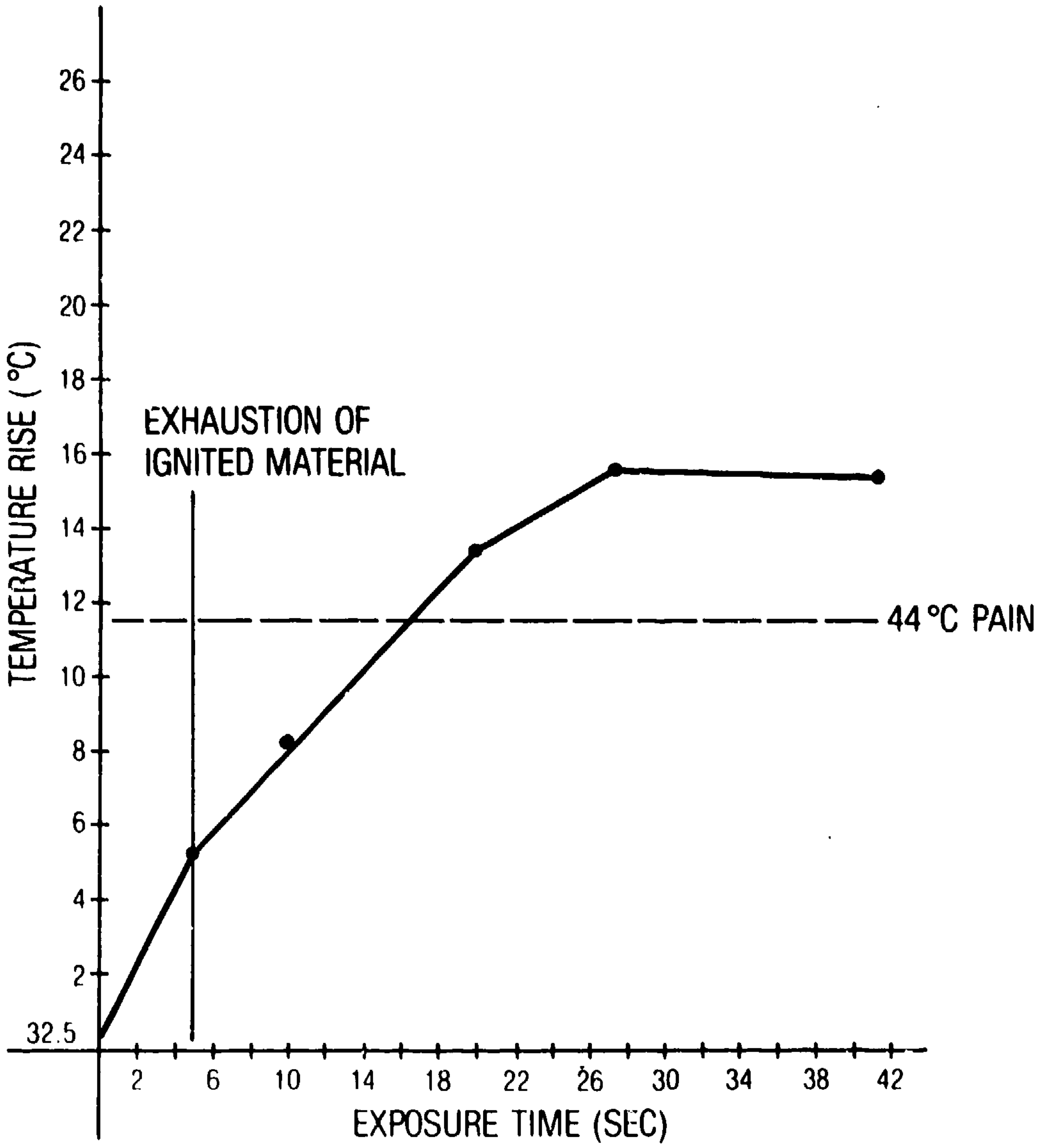

Figure 18. Temperature Rise Above Ambient Temperature With Time as Measured by Skin Simulant, No. 36 Semi-Carbon Fabric/Kynol Felt/PTFE Nomex Fabric, TPR, 15.

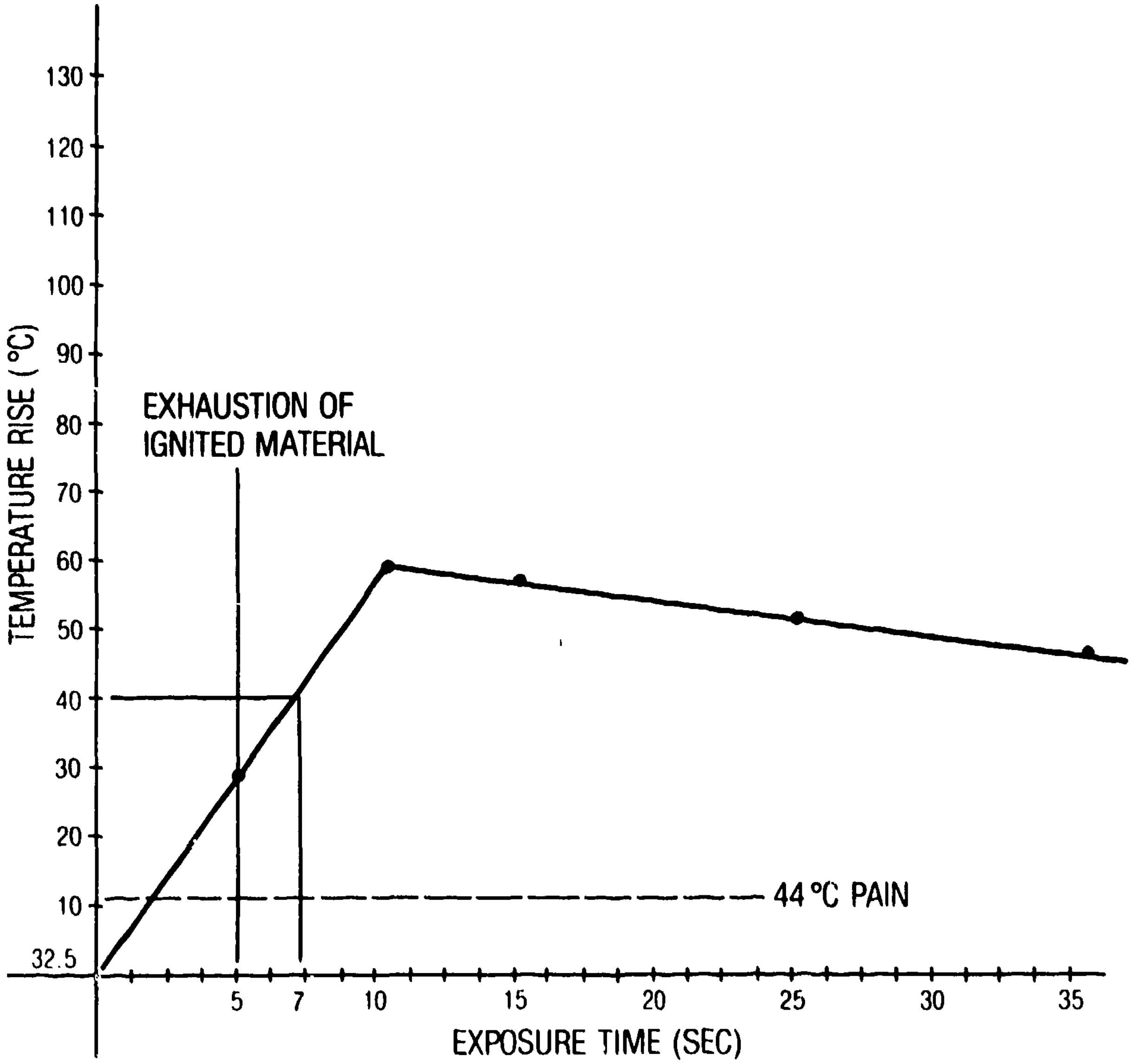

Figure 19. Temperature Rise Above Ambient Temperature With Time as Measured by Skin Simulant, No. 37 Semi-Carbon Fabric/Rayon-Wool Felt/PTFE Nomex Fabric, TPR, 1.5.

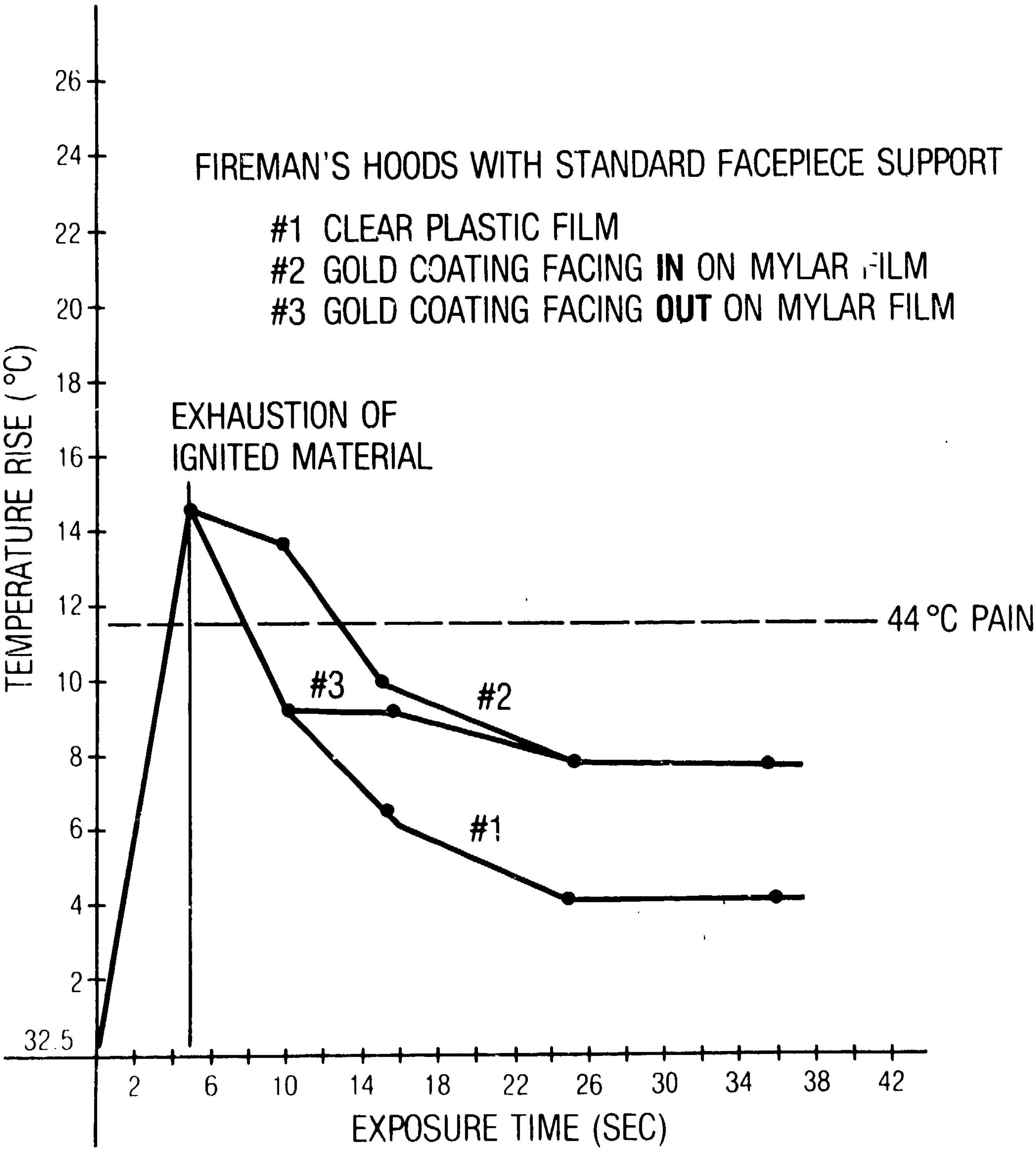

Figure 20. Temperature Rise Above Ambient Temperature With Time as Measured by Skin Simulant, Clear and Gold-Coated Plastic Faceshields.

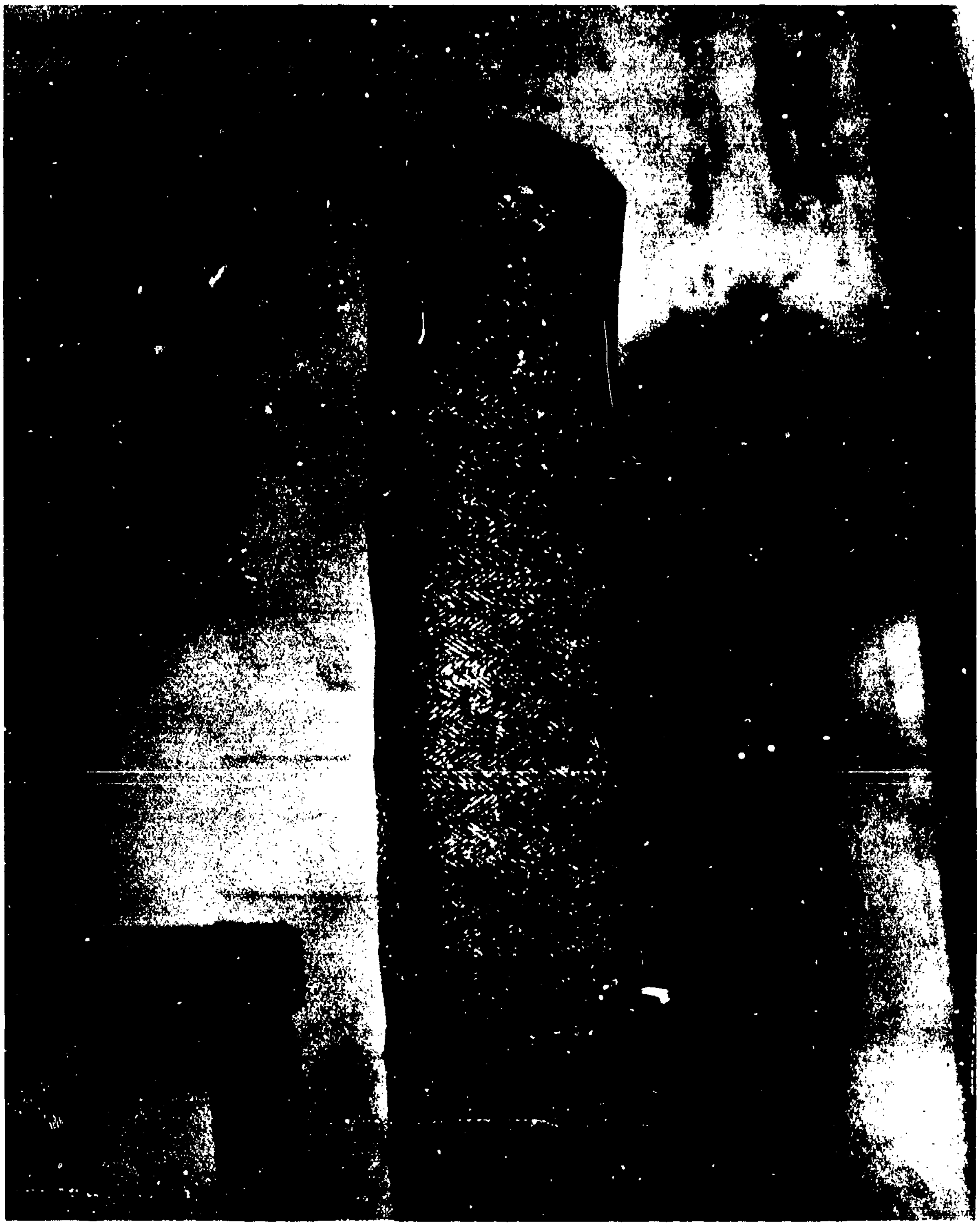

Figure 21. Assembly No. 24: Outershell, 80% OPF/20% PBI; Insulation Liner, 100% Kynol Batt; Moisture Barrier Liner, PTFE/Nomex, 3.6 oz/yd^2.

Figure 22. Assembly No. 28: Outershell, 80% OPF/20% PBI;
Insulation Liner, 100% Nomex Batt, 7 oz yd^2;
Moisture Barrier Liner, PTFE/Nomex, 3.6 oz/yd^2.